/ 14.1829.

PRINCIPLES

OF

NATURAL PHILOSOPHY:

OR,

A NEW THEORY OF PHYSICS,

FOUNDED ON

Gravitation,

AND APPLIED

IN EXPLAINING THE GENERAL PROPERTIES OF MATTER,

THE PHENOMENA

OF

CHEMISTRY, ELECTRICITY, GALVANISM, MAGNETISM, & ELECTRO-MAGNETISM.

BY THOMAS EXLEY, A.M.

ASSOCIATE OF THE BRISTOL PHILOSOPHICAL AND LITERARY SOCIETY.

"*Felix qui potuit rerum cognoscere causas.*"—VIRGIL.

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TO

ADAM CLARKE, LL.D., F.A.S.,

MEMBER OF THE ROYAL IRISH ACADEMY; OF THE GEOLOGICAL SOCIETY OF LONDON; OF THE ROYAL ASIATIC SOCIETY OF GREAT BRITAIN; &c. &c. &c.

SIR,

Your high attainments in Literature, and your uniform endeavour to promote the acquisition and extension of Useful Knowledge, in the various departments of Science, have always yielded me much pleasure, and raised you high in my estimation, and in the estimation of many others; and, during the period of more than thirty years in which I have had the honour and happi-

ness of a family connection with you, I have experienced your unremitted friendship and kindness, and have reaped great advantage from your advice and encouragement.

For these and similar reasons, I dedicate to you this Volume, the result of much labour and thought; and am solicitous that you would accept of it as a small tribute of my gratitude and respect.

THOMAS EXLEY.

BRISTOL, *March 1st*, 1829.

INTRODUCTION.

THE office of natural philosophy is, to enquire into the phenomena of material beings, and to ascertain their causes.

Experiments and observations form the true basis of philosophy: by these we become acquainted with the phenomena, and are directed to the powers or causes, which produce them; and having discovered these, we frequently observe, that they are the results of more general causes; which, being themselves discovered, become principles in the explication, not only of those phenomena by means of which they are determined, but also of all others to which they are applicable; and when they are found adequate to this purpose, the principles themselves are established.

To assist our enquires of this nature, Sir *I. Newton* has furnished the following excellent rules, at the commencement of the third Book of the Principia.

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RULE I. "We are to admit no more causes of natural things, than such as are both true, and sufficient to explain their appearances."

RULE II. "Therefore, to the same natural effects we must, as far as possible, assign the same causes."

RULE III. "The qualities of bodies, which admit neither intension nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever."

RULE IV. "In experimental philosophy we are to look upon propositions collected by general induction from phenomena, as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions." (See *Motte's* Tran. vol. ii. p. 202.)

Matter, which in its various states and forms, is the subject of natural philosophy, is perceptible to man by means of its powers, acting on the senses, which evidently, in infinite wisdom, are adapted to receive the impressions of these powers: powers which themselves are in continual operation, and appear to constitute the very essence of matter; for, from these, all its other universal properties as far as they are discovered, may be derived, while those properties themselves, cannot result the one from any other of those which are

known; neither can the less general properties be derived from any of them, or from each other.

These powers are denominated attraction and repulsion. Their nature is not known, but the laws of their operation have been at least partially developed: that both these belong to matter is incontrovertible; did attraction exist without repulsion, matter would be conglomerated into one body, and if there were repulsion only, all bodies would be universally dispersed, supposing them to consist of separate particles.

Universal experience and careful observation, shew, that bodies at rest have a tendency to remain at rest, and those which are in motion to continue that motion uniformly in a straight line; were there no tendency of this kind, there would be no such changes in the state of bodies as we observe, and the resistance, which bodies are known to oppose to forces or powers applied, could not exist.

Not only when bodies are acted on in opposition to gravity, or their descent towards the earth, is this resistance experienced, but even in that very direction, for any force, applied to make a descending body move more swiftly downward, is resisted in proportion to its quantity, and the same is true in every other case.

But we find, that the great and distant bodies of the solar system are continually deflected from the line of their direction, into curves concave towards the sun, which is included within their

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orbits, and situated in the planes of those orbits: hence they are attracted or acted upon by some force directed towards that quarter; in a similar manner are the secondary planets urged towards their primaries, and observation shews, that all these bodies tend towards each other; hence they disturb each other's motions, producing several apparent irregularities. And we find also that the attractions of the moon, of the sun, and by consequence, even those of the planets, disturb the equilibrium of the waters of our globe, and cause the ebbings and flowings of the ocean and their variations.

Also, all the parts of the earth are held together by the principle of attraction; since, were it not for this force, the motion of the globe on its axis would disperse its parts, and the least effort applied, would crumble the hardest bodies to powder, if indeed, we could suppose the existence of hard bodies.

Every one must have observed, that the parts of bodies tend to each other, because it is continually apparent, from the globular figure, which small portions of liquids, as water, oil, mercury, &c., assume; and from the ready union of two or more small drops into one larger drop; and this shews, that not only those atoms, which are contiguous, act on each other, but likewise that a similar action continually operates between those particles, which are on the opposite sides of the drop.

The same is shewn by the ascent of water in fine glass tubes, on the sides of vessels, into the interstices of sand, ashes, and other porous bodies, as also by its absorption by sugar, spunge, salt, &c.; and again, we see that when melted metals, wax, resins, sulphur, &c., are cooled, their parts unite and form solid masses, and the same happens to water, and even to mercury, when at a sufficiently diminished temperature.

Thousands of instances presenting the universality of such action between bodies and their parts, might be adduced from the phenomena of chemistry, electricity, magnetism, &c.; shewing that the principle of attraction pervades the natural world, and is found wherever matter is found.

How near to the centers of the atoms of matter this force of attraction extends from all sides of that center, has not been ascertained; but at distances very near the center, an opposing force, called repulsion, has been observed, which force prevents the perfect coincidence of those centers, and consequently of the parts of bodies.

Nor, is the power of repulsion less universal, than that of attraction; in no other way can we account for the easy motions of the parts of fluid bodies, one amongst another, whether liquids or gases: and it is to be noticed, that the various solid bodies are capable of the liquid form.

The parts of all bodies may be brought nearer together by the application of force; bodies con-

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The parts of all bodies may be brought nearer together by the application of force; bodies con-

tract by cold, and expand by heat, which indicates repulsion; the compression, and subsequent expansion of elastic bodies shew the same, and no bodies are found altogether void of elasticity. If a convex lens be placed on a plane surface of glass, its weight is not sufficient to bring the surfaces into contact, nor can this be perfectly effected by any force we are able to apply; besides which, we have innumerable instances of this repulsive force, in every department of the material world; destitute of this, not a single atom of matter has ever been found or exhibited; and, although, some phenomena may possibly appear to be accounted for, independently of repulsion, as belonging to every atom of matter; yet the explications rest on feigned hypotheses, and no phenomenon of nature contradicts the supposition that this principle is as universal as matter itself. Therefore, by the rules of sound philosophy, we must admit the universal influence of both attraction and repulsion.

The attraction, which takes place between the distant bodies of the universe, (and which is clearly ascertained to be the same as that power called gravitation, by which bodies descend towards the earth,) varies, in intensity, directly as the quantity of matter, and reciprocally as the square of the distance of the attracting bodies. Sir *Isaac Newton* has left no doubt on this subject. See the Principia, and *Cotes'* excellent Preface; and, also, consult the Authors who have since written on

physical astronomy, where it will be found that the truth of these laws is fully established. But the illustrious *Newton* and others, have concluded that the attraction, by which the particles or atoms of bodies adhere together, observes a different law, and decreases at a greater rate. The 85th *prop. Book* i. of the Principia, is intended to prove this, for which purpose the 70th and 74th *propositions* are employed.

It should, however, be carefully observed, that the hypothesis of this beautiful theorem requires the attractive forces to be directed to *every point* of the sphere ; but, in every point of a body, even in the view of that great and distinguished philosopher, there are not atoms situated ; since he admits that the most dense bodies contain more vacuity than solid parts ; hence the proposition does not apply in nature ; and it is surprising that *Newton's* penetrating genius did not perceive this fact. Let only a small distance be admitted to exist between the atoms of bodies, and then a particle may be placed among them, so that it shall be attracted by its contiguous particle, with a force indefinitely greater than it is attracted by all the other particles of the body put together, on the hypothesis, that the forces vary inversely as the square of the distance.

The 74th *proposition* of the Principia will hold good in nature, because it is not requisite in this case, that the forces should be directed to every

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The 74th *proposition* of the Principia will hold good in nature, because it is not requisite in this case, that the forces should be directed to every

point of the body, it being sufficient that the several attracting points be symmetrically arranged.

Again it has been said, that the attraction of cohesion, at a small increase of distance, is changed into repulsion; thus, when a piece of glass is broken, and we attempt to replace the fragments, there is a repulsion, and the parts cannot be again forced so near together, as they were before the fracture, the parts being now removed into the sphere of each other's repulsion. But here again, we ought to observe, that the surface and pores of glass and other bodies are replete with a fine elastic fluid, which by attraction adheres to those parts of the corpuscles to which it can gain access; and as soon as the glass, or other body, is broken, the particles of this elastic fluid diffuse themselves, by their mutual repulsion, over the surfaces exposed by the fracture, as will be more fully explained in its place; and these atoms of ethereal matter so diffused by their repulsive forces, will prevent the re-union. Various kinds of attraction have been supposed to exist, but every kind, not excepting electrical and magnetical attractions, may be explained without having recourse to any attraction, but that of universal gravitation, affecting every atom of matter of every sort after the same manner, and according to the law above mentioned, as will be seen on consulting the different Sections of this Work.

Many opinions have also been entertained respecting these powers, especially repulsion; some philosophers are persuaded that the atoms of matter have several spheres of repulsion and attraction, succeeding each other alternately: others have supposed, that repulsion acts between the atoms of matter at sensible distances; and others again conclude, that caloric is the sole cause of repulsion. Caloric has been considered as the only agent in repulsion at minute distances; it has been called "the *repulsive* power, which constantly acts in opposition to the power of attraction, or chemical affinity." *Parke's* Chem. Catechism, p. 88.

Some have considered the law of repulsion as unknown; others state that it varies inversely as the square of the distance; and others, that at the least, in some cases, it varies inversely as the distance. It is now generally admitted, that repulsion is as universal as attraction.

Without this power elastic bodies could not recover the figure and state, which they had before compression. Its action must be perpetuated between every two atoms of matter, otherwise they would adhere inseparably in complete contact; for so minute are the smallest parts of matter known to be, that the attraction between them, if in contact, would be indefinitely great. It cannot, however, be shewn, that repulsion varies by any other law than that of the square of

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the distance inversely. It is indeed ascertained by careful experiment, that when dry air and other gases are gradually compressed, their densities vary as the compressing force; and from this it has been inferred, that the repulsive power of the atoms of gases varies inversely in the simple ratio of the distance of the atoms. This inference rests on the supposition, that all the repelling atoms continue in the compressed gas, and without this it cannot be true.

Now during the compression, much caloric, which is universally allowed to be of a repulsive nature, escapes from the compressed gas; and from this well known fact, it clearly follows, that the repulsive force of the atoms of gas increases inversely as some higher power than that of the simple distance, probably as that of the square of the distance inversely; that is, according to the same law which regulates the force of attraction. For a more particular view of the effects of the compression of gases, see *ph.* 17, *sect.* iv. We have no instance of the repulsion of matter at sensible distances, although attraction is known to act at least to the utmost boundaries of the solar system, and probably indefinitely beyond those boundaries. It might indeed be said, are not electrical and magnetical repulsions instances of the operation of this force at considerable distances? I answer,—By no means; these apparently distant repulsions are more naturally and

clearly explained by the operation of repulsion at insensible distances, (see *Electrical Phenomena, sect.* vii.); and so is also the apparent repulsion between two balls on the surface of a liquid, (see *ph.* 24, *sect.* v.) Electrical and magnetical attractions and repulsions are considered as being of a peculiar and specific nature.

In order to explain electrical phenomena, many hypotheses have been advanced. The two principal of these have been modified, and greatly improved, and philosophers are yet divided in their opinions as to the merits of these electrical theories: many of the phenomena are solved by both, and nearly with an equal degree of facility and elegance. The one is Dr. *Franklin's* Theory reduced to precision, and much improved, by *Epinus;* and also by the Hon. Mr. *Cavendish.* See his Paper in vol. lxi, of *Philosophical Transactions.* This Theory, in its improved state, admits of one distinct electric fluid, such that, 1. Its particles mutually repel one another, even at sensible distances. 2. Its particles attract those of all other bodies, and are mutually attracted by them at sensible distances. 3. The attraction of one of two electrical bodies, and the fluid of the other, when both are in their natural state, is equal to the mutual repulsion of the fluids; that is, of the fluid of one body upon that of the other. 4. That the same attraction of the first body on the fluid of the second is equal to the attraction of the second

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clearly explained by the operation of repulsion at insensible distances, (see *Electrical Phenomena, sect.* vii.); and so is also the apparent repulsion between two balls on the surface of a liquid, (see *ph.* 24, *sect.* v.) Electrical and magnetical attractions and repulsions are considered as being of a peculiar and specific nature.

In order to explain electrical phenomena, many hypotheses have been advanced. The two principal of these have been modified, and greatly improved, and philosophers are yet divided in their opinions as to the merits of these electrical theories: many of the phenomena are solved by both, and nearly with an equal degree of facility and elegance. The one is Dr. *Franklin's* Theory reduced to precision, and much improved, by *Epinus*; and also by the Hon. Mr. *Cavendish*. See his Paper in vol. lxi, of *Philosophical Transactions*. This Theory, in its improved state, admits of one distinct electric fluid, such that, 1. Its particles mutually repel one another, even at sensible distances. 2. Its particles attract those of all other bodies, and are mutually attracted by them at sensible distances. 3. The attraction of one of two electrical bodies, and the fluid of the other, when both are in their natural state, is equal to the mutual repulsion of the fluids; that is, of the fluid of one body upon that of the other. 4. That the same attraction of the first body on the fluid of the second is equal to the attraction of the second

body on the fluid of the first. 5. That the particles of the two bodies, imbued with electricity, repel each other, so that, when in their natural state, the sum of the attractions of each body on the fluid of the other is equal to the sum of the repulsions of the two portions of fluid, and of the particles of the two bodies.

The other Theory, is that of *Du Fay*, improved by M. *Coulomb;* it is embraced by many modern philosophers of the first rank, and supposes the existence of two peculiar electric fluids called vitreous and resinous, such that, 1. The particles of the same fluid mutually repel one another at sensible distances. 2. That the two different fluids attract each other at a considerable distance. 3. The particles of each fluid are attracted by those of all bodies. 4. That if two bodies be in their natural state, the vitreous fluid of the one attracts the resinous of the other, as much as the resinous fluid of the first repels it, and again, in like manner, the resinous fluid of the first attracts the vitreous fluid of the second, as much as the vitreous fluid of the first repels the vitreous of the second.

It is not my province to decide on the merits of these hypotheses; there is certainly a great want of simplicity in the supposition of two fluids, especially when we are obliged to give such similar, and at the same time opposite, qualities to them The first theory also labours under a great

objection by requiring, that the particles of distant bodies should act on each other by repulsion. Also there is a great want of simplicity in both, by requiring repulsion, and perceptible attraction, at sensible distances.

Both these theories, in the present Work, are totally discarded, as altogether unnecessary, and also as being quite inadequate to explain many electrical phenomena.

There is doubtless an electric fluid, or ethereal matter, concerned in all the appearances exhibited in electricity; but there is no need to attach to it any peculiarity, or to suppose that it differs from other matter, except as other kinds of matter differ from each other, *viz.* in the force of their atoms, and the magnitude of the sphere of repulsion.

In the Explanations given in the several parts of this Work, no repulsion of any kind is allowed at sensible distances, except that which is apparent only, and produced by the medium of adjacent matter; nor is there admitted any *perceptible* attraction of single atoms, particles, or small masses, on each other at sensible distances; for although it is stated that every atom of matter attracts every other, even at immense distances; yet, the attractions of the few atoms which are contained in the bodies, which we employ in our experiments, are so small, that, even unitedly, the effects of their actions at sensible distances are not per-

ceptible. It will be found, that in this performance, no peculiar electrical theory is substituted, for those which are thus freely dismissed as inefficient, and it is confidently expected, that the Reader will find the electrical phenomena clearly explained, including many, which, it is allowed, that neither the theory of one fluid, nor that of two, as mentioned above, can solve. Similar observations might be made respecting Galvanism, Magnetism, and Electro-magnetism, which have still more puzzled the enquirers into nature; no new theory is here advanced, in order to unfold the mysteries of these Sciences; and yet, perhaps, it will be found that their several phenomena are as clearly accounted for, as by the most refined speculations, which have been directed to this subject. Nay, had not the Author thought the explications better, and more general, without additional principles, and separate theories, than with them, his present labours would have been concealed from the eye of the Public. How far he is right in his sentiments does not, however, now belong to him to judge.

The Explanations throughout the Work, are to be considered as resting on the general theory of physics laid down at the commencement; no principles are required but those which are presented to the Reader, and such as are fairly deduced from them; these of course the Reader is expected to admit as the ground-work. And

here no postulatum will be found, but such as in the present state of philosophy may be readily admitted, being, indeed, less than claimed and granted in other performances; for the Reader has only to allow that each atom of matter consists of an indefinitely extensive sphere of attraction, resting on a very small concentric sphere of repulsion, the force being every where, from the center, inversely as the square of the distance, repulsive near the center, and then attractive. Now that part which regards the attraction has already obtained the consent of all the followers of *Newton*, and much more than the other part, which respects repulsion, has been already received in the principles of our present philosophy.

It may be here asked,—Are we absolutely to exclude solid atoms? I confess I can find no use for them. It is true Sir *I. Newton* thought that the atoms of matter consisted of minute solids, as appears from the following beautiful paragraph taken from the closing part of his incomparable Treatise on Optics.

"All these things being considered, it seems probable to me, that God in the beginning formed matter, in solid, massy, hard, inpenetrable, moveable particles, of such sizes and figures, and with such other properties and in such proportion to space, as most conduced to the end for which he formed them; and that these primitive particles, being solids, are incomparably harder than any

porous bodies compounded of them, even so very hard as never to wear or break in pieces: no ordinary power being able to divide what God himself made one in the first creation. While the particles continue entire they may compose bodies of one and the same nature and texture in all ages: but should they wear away, or break in pieces, the nature of things depending on them would be changed. Water and earth composed of old worn particles and fragments of particles, would not be of the same nature and texture now, with water and earth composed of entire particles in the beginning. And therefore that nature may be lasting, the changes of corporeal things are to be placed only in the various separations and new associations and motions of these permanent particles; compounded bodies being apt to break, not in the midst of solid particles, but where those particles are laid together, and only touch in a few points."

The atoms of matter constituted as in the theory now proposed, possess all the individuality, indivisibility, and indestructibility, which the learned and illustrious *Newton* ascribes to his small solids, and they answer all the ends he has mentioned; the central points, indeed, will be utterly impenetrable by each other, since the repulsion there, is infinite; and if at those centers we suppose small solids to be placed, they can answer no farther end than is accomplished by this immensely great repulsive

force; for from what we know of matter, we must suppose them to be indefinitely small, if we introduce such solids: and hence they will occupy the place where the repulsion is indefinitely great: such solids would be found only an obstacle, and an encumbrance to the free actions of matter; since, however small we imagine them to be, their magnitude will be infinite if compared with a mathematical point, the center of an atom, which is devoid altogether of magnitude. It may be added that, if any Reader wish to retain these solids at the centers of the atoms, it will not materially affect the conclusions, provided he allow us to have them as small as we please; and so much, if he intend to philosophise, he must grant, whatever course he may determine to pursue.

It will be perceived that this theory is in some respects allied to that of the celebrated *Boscovich;* the first sphere of repulsion, and the extreme sphere of attraction of that philosopher are retained; but the intermediate alternate spheres of attraction and repulsion are rejected. The explication of the various appearances, or phenomena of natural bodies, do not seem to require them. The *Newtonian* rules do not allow us to multiply causes, nor to admit of any, which the necessity of the case does not demand. The proposed theory is not framed at random, it has been suggested by the voice of nature; the labours of

modern philosophers have contributed to its adoption; these labours which have been continued through the last, and the preceding part of this century, have wonderfully extended the boundaries of science: knowledge has been abundantly encreased by means of careful experiments, and accurate observations, forming the basis of all sound philosophy. Without these we theorise in vain; but the results, which these furnish, tend continually to bring us nearer to the true and complete view of the operations performed, and carried on without intermission in the various parts of the universe.

Whoever has entered deeply into these subjects, is well aware, that nothing is to be *arbitrarily* assumed as a principle, except by way of enquiry and trial, and he will perfectly agree with *Newton* in the following observation, "Whatever is not deduced from phenomena, is to be called an hypothesis: and hypotheses, whether physical or metaphysical, whether of occult qualities, or mechanical, have no place in experimental philosophy." The essential nature of what we call attraction and repulsion does not concern us: that certain powers exist, which are called by these names, is manifest to every enquirer into the constitution of bodies: but we are not to create different kinds of these powers at pleasure, in order to solve every new and knotty subject of investigation.

Before a new kind of operating power is sanctioned, let its existence as a fact, and as a principle be well established. There can indeed be no great harm in bringing hypothetical views to bear on a subject, provided they be stated as such.

But it seems to be getting again too much in fashion in the philosophical world, to multiply hypotheses, and to call them theories. The present Work cannot, it is hoped, be accused of the fault here specified, for as we have stated, and as the Work will shew, no new principle is introduced: on the contrary, several which have been considered, as almost, if not quite established, have been rejected.

It may be said, Why then is this called a new theory? I have ventured so to denominate it, not from an introduction of new principles, but from a new application of those, which have been most solidly established. These, and the experimental facts brought into view, by the united efforts of scientific men, are here placed before the Reader in a new light. The theory itself, and the deductions from it are first laid down as concisely as the subject seems to admit: then follow the explanations, of some of the most important phenomena of the material world, which have exercised the human intellect; and the exposition of these, it is presumed, will afford a key for opening the more secret recesses of nature.

The facts are collected from works of the high-

est reputation, they are generally such as are well known; hence it has not been thought necessary to quote the authors, from whom they are selected, or to state by whom they were discovered, except in a very few instances. This is properly done in so many different Treatises, that the Reader will not be at any loss to satisfy himself on this head.

Care has been taken to state the phenomena in a concise, plain, and perspicuous manner; after which is immediately subjoined to each, the explanation; and it is this part which is founded on the theory, without reference to other principles.

When the multitude of facts which are brought forward, in very different branches of philosophy, and their diversity, are considered; some difficulty must be allowed to have occured in bringing so few and such simple principles to bear in the explanations. But, if the principles be found to succeed, even as well as when the phenomena are made to depend on separate theories, invented chiefly for the purpose of explaining them: they must be received at least as being probable, rational, and worthy of special notice. It is not complexity, but simplicity, which characterizes the operations of nature, in all their multiplicity, diversity, and grandeur.

To use the words of a late writer, "How simple and yet how wonderful are the works of nature? Such like are all the effects of infinite wisdom, her

foundations are plain and simple, her superstructure, various and wonderful. Her causes few, her effects innumerable. Her course the easiest and shortest possible, and her means, the fewest that can possibly bring about her ends." The sublimity and profundity, with the almost infinite variety, as well as constancy and uniformity, which we cannot but notice, when we attentively observe the open and more concealed processes continually presented in nature on a grand scale, lead us to look for causes and powers almost as diversified as the effects. It is found, however, that the more fully and deeply we enter into the enquiry, the more we become satisfied, that the simplicity of the first principles, is as much calculated to excite admiration, as the infinity of the results.

It was in attempting to explain Electrical phenomena that these views were first apparent, and they seemed to be confirmed on finding that the reflection, refraction, and inflection of light could also be rendered intelligible by the same simple means. I had it in contemplation to introduce the subject of Optics, but this has been omitted for two reasons; first, the publication must have been delayed for some considerable time, because the duties of my profession afford me but little leisure for writing; and secondly, the plan of the Work in that case, would have been pursued under a form less popular, and more adapted to mathematical Readers. Besides, what is here offered to the

Public, will be sufficient to enable the learned to decide on its merits: and should it appear worthy of notice, I shall be encouraged to apply the same principles in the explication of the phenomena of light and colours, unless this part should be undertaken by some philosopher more adequate to the task.

It may not be improper to mention at the close of this Introduction, another circumstance which has frequently called my mind to the consideration of the constitution of matter. It is, that of noticing the assertions of a certain author, alleging the impossibility of the creation or annihilation of matter. He says, "That to give existence, is to act. This cannot be but by the application of force, which the acting being produces. If there be not a subject at all, on which the acting power can apply its force, it cannot have any action; for to act, or to exercise a force, and to exercise it on nothing, is a contradiction." From this he concludes, that a creating power is impossible, and that matter is eternal.

Reflecting on these sentiments, I found no difficulty in conceiving, that a Being, infinite, in power, and wisdom, and every way perfect, could enclose or fence up a small or large space by invincible power, so that none but himself could break the barrier, and towards this, or from it, he could direct any powers he pleased; and as he could thus produce one atom, so equally he

could bring into existence an endless variety and multitude, and this presents us with the most common and familiar idea of matter. Again, there is nothing incongruous in the idea, that such a Being could direct a power every way from a central point to any distance he pleased; and towards the same point he could exercise a power contrary in direction, and resting on the former, and this would constitute an atom having all the properties which we observe in the elements of matter. If then the finite mind of man, can discern two ways in which matter could be created, are there not an infinity of ways present to the Divine Mind!

It is true this supposes, that matter exists continually by the power of its great Author. And certainly this must be admitted; the same power which produced its existence is unremittingly requisite for the continuance of its being, so that, he not only made all things, but upholdeth all things, by the word of his power. This circumstance, although it may not be considered as necessarily connected with our subject, is mentioned, as having been a stimulus in directing my views to a serious consideration of its bearings.

In natural philosophy it is not so much our business to enquire how the world might have been framed, as how it is in reality constituted; we are not to be world-makers or world-menders; to contrive a system of notions and schemes, and form

our views of nature by such means as we derive from them; but our work is to consider things as they are, to pursue the effect to its cause, and the cause to its effect, as far as these can be brought within the reach of our senses, and hence to raise our notions of things from realities. And thus shall we be led from nature up to nature's God, from which elevation we shall behold the wonders, the beauties, and the perfections of his works with inexpressible delight.

It was my intention, at the commencement of these Principles, to treat the several subjects under a mathematical form, and for this purpose I had prepared a series of propositions to be applied in different cases; but on reflection I perceived that this method would render the Work less interesting to numerous persons, who are not conversant in mathematical investigations, and yet have a large acquaintance with many branches of physical knowledge, and who would probably find great pleasure and advantage in the contemplation of these important subjects, when treated in a plain and familiar form. This has induced me to adopt the present mode of explaining the several phenomena, which are here collected. I have endeavoured to be concise, and at the same time perspicuous; if I have succeeded in this point, I fear from no other quarter.

CONTENTS.

SECTION I.

SECTION II.

The Theoretical Constitution of Matter.

SECTION III.

SECTION IV.

Properties of Bodies and Change of Form.

SECTION V.

Cohesion, Repulsion, and Crystallization.

SECTION VI.

CHEMISTRY.

SECTION VII.

ELECTRICITY.

SECTION VIII.

GALVANISM.

SECTION IX.

MAGNETISM.

SECTION X.

ELECTRO-MAGNETISM.

Plate 1.

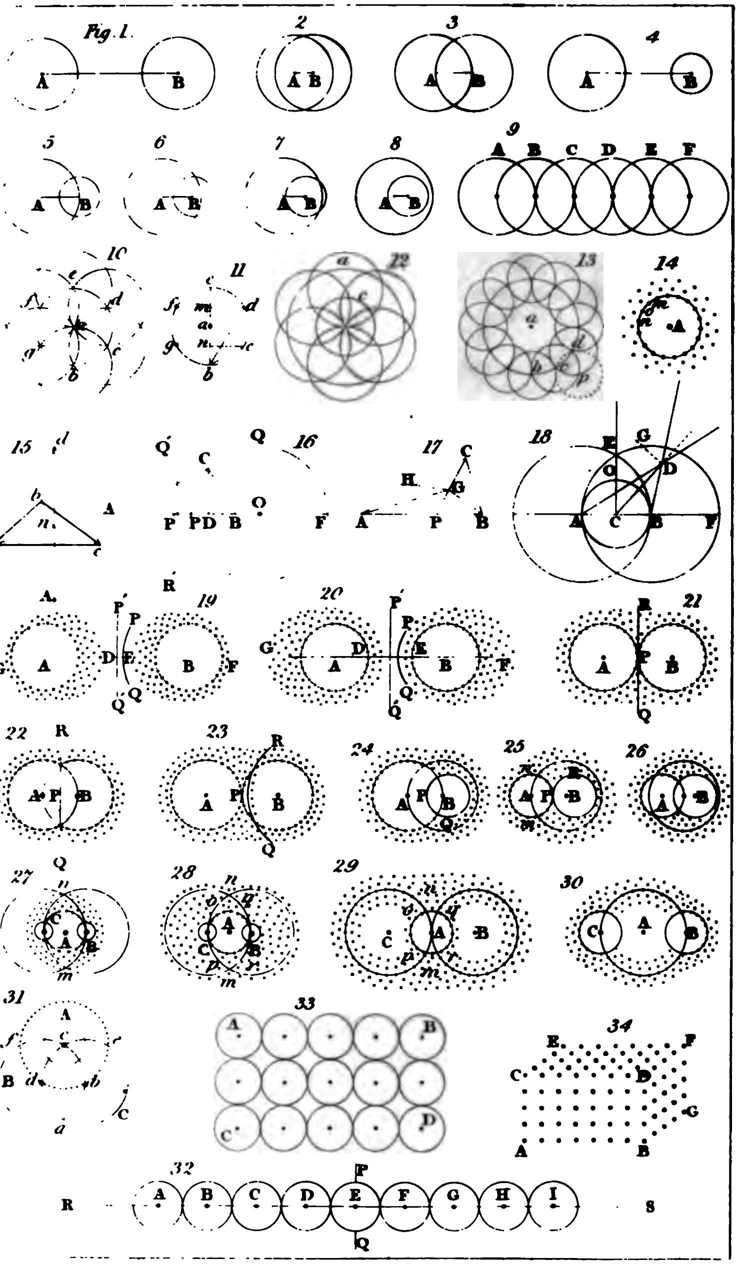

Plate 3.

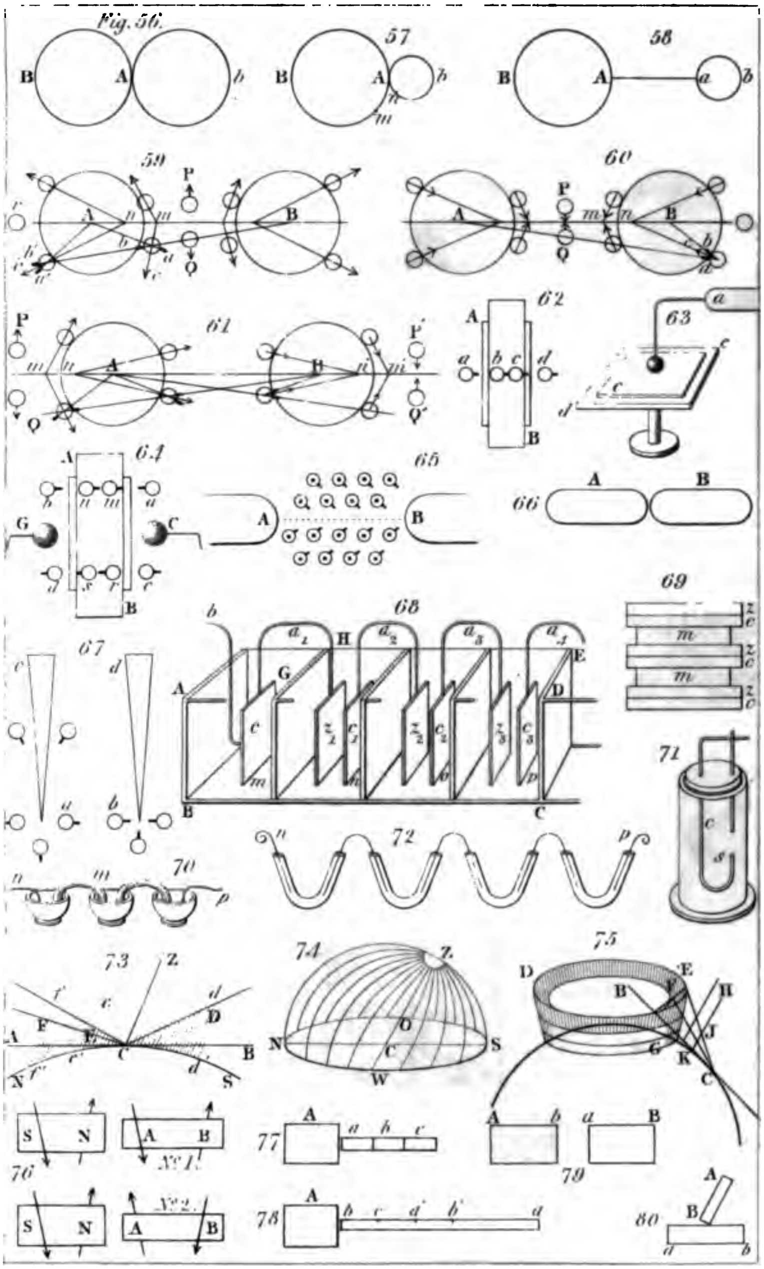
Fig. 56.
57
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59
60
61
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No. 1.
No. 2.
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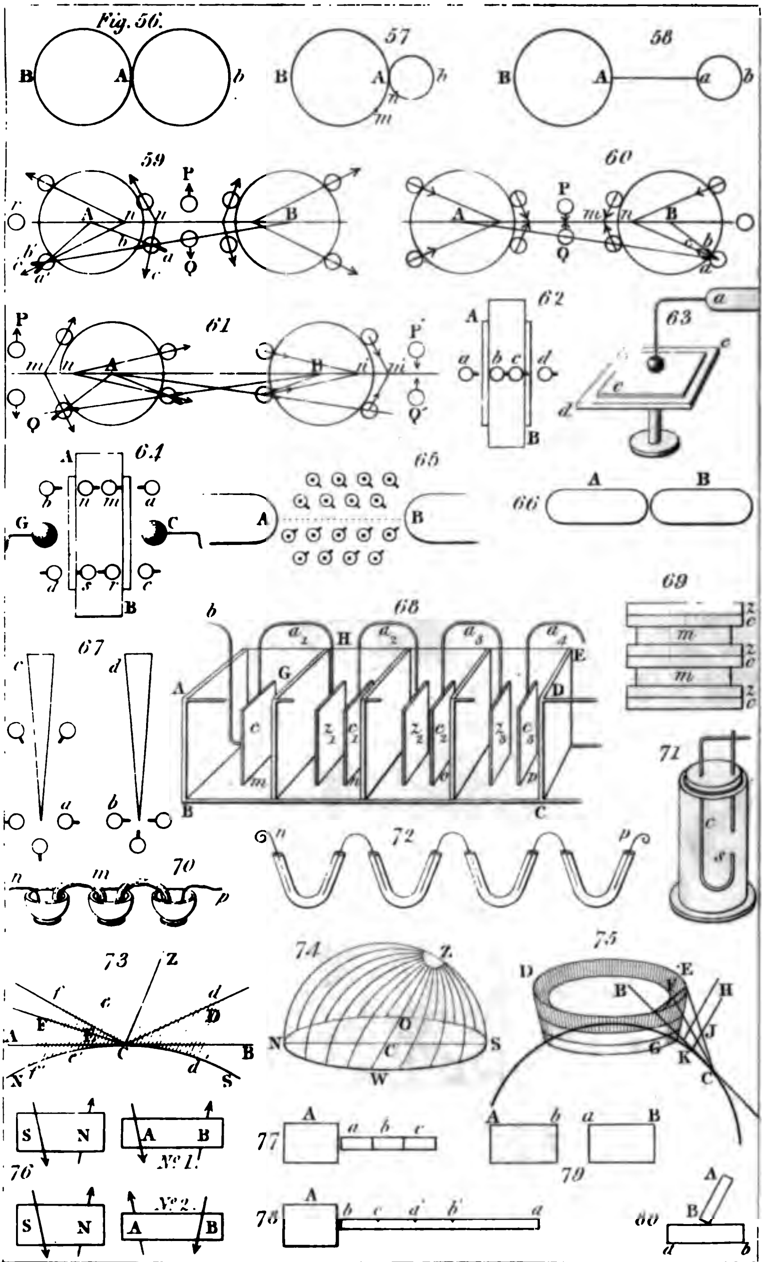
Fig. 56.
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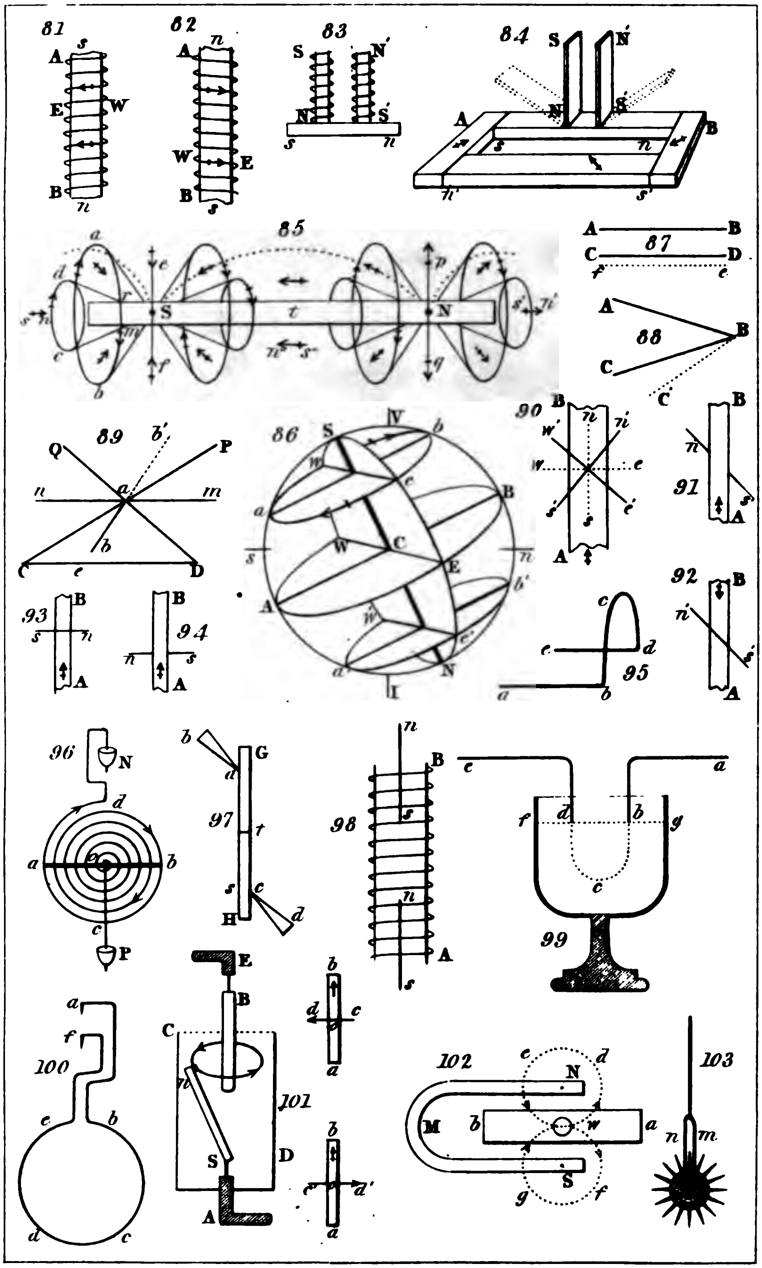
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82
83
84
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86
87
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90
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92
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94
95
96
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98
99
100
101
102
103

PRINCIPLES

OF

NATURAL PHILOSOPHY,

&c. &c.

SECTION I.

Definitions, Postulates, and Axioms.

Definition 1. Matter is that substance which we perceive by the senses.

2. An atom is an element of matter, such as cannot be divided without destroying its nature.

3. A particle is two or more atoms so united as to form a distinct element of matter, such as cannot be divided by common mechanical agency.

4. Body is a collection of simple atoms or particles considered in themselves together; and apart from other matter.

5. A corpuscle is a very small body, existing either separately, or as making a part of a larger body.

6. Motion is that which we notice in a body, when we attend only to its progress or passage from place to place.

7. Velocity is the motion of a body measured by the space passed over in a given time.

8. Uniform or equable motion is when the velocity is always the same.

9. Variable motion is when the velocity changes.

10. Direction of motion is the line in which, or parallel to which, the motion is performed.

11. State of a body at any time is its rest or uniform motion in its direction at that time.

12. Force is that which changes, or tends to change, the state of any body or portion of matter.

13. When a force acts at an instant only, it is called an impulse; when it acts constantly, it is called a constant force.

14. Momentum is the force by which a moving body can strike against an obstacle.

15. Moving force is measured by the momentum it produces.

16. Accelerating force is measured by the velocity it produces.

17. Affinity is the force by which two or more atoms or particles unite so as to form a new particle, and cohesion is the force by which the particles adhere so as to form a body consisting of like particles.

18. Attraction is a centripetal force; that is, a force directed *towards* some point of a body or center of an atom.

19. Repulsion is a centrifugal force; that is, a force whose direction is *from* some point of a body or center of an atom.

20. Sphere of attraction or repulsion is the space in which the force operates.

21. Equilibrium is that permanency in its state of any thing moveable, when acted on by more forces than one, which mutually and equally counteract each other.

Postulate 1. Let it be granted that an atom of matter consists of an indefinitely small sphere of repulsion, which is the central part of an indefinitely extended concentric sphere of attraction; and that its force on the centers of other atoms, every where within the compass of its action, varies inversely as the square of its distance from the center, being attractive at all points beyond the sphere of repulsion, and repulsive at all points within that sphere. See note (A).

Corollary 1. At the surface of the sphere of repulsion there is neither attraction nor repulsion, but an opposition to an approach or to a separation; at all other concentric surfaces, the sums or total forces are equal: for these surfaces are directly as the squares of their distances, and the forces are inversely as the squares of those distances; hence the compound ratio is that of equality.

Cor. 2. Hence the force, at the center of an atom, is equal to the sum of all the forces in any spherical surface whose center is that of the atom.

Pos. 2. Let it be granted that atoms may differ from each other, in the radii of their spheres of repulsion, and in their forces at a given distance from their centers.

Def. 22. The sphere of repulsion of an atom is called its spherule.

23. The sphere of attraction of an atom is called its expanse.

24. Absolute force of an atom is its force at a given

distance from the center, and this is called its mass or quantity of matter.

25. Mass or quantity of matter of *a body*, is the aggregate of the matter of the atoms whose spherules it contains.

26. Density is measured by the quantity of matter in a given space.

27. Inertia is the inability of matter of itself to change its state.

28. *Vis inertiæ* is the force which matter opposes to that force, which changes its state.

29. The point in which the center of an atom is situated, is called the place of that atom; and the distance of a point from an atom is its distance from the center of that atom.

Scholium. The radius of the spherule, for the sake of convenience, is sometimes called the radius of the atom; and the atom, when no ambiguity would arise, may be understood to mean the spherule.

30. Atoms are said to be of the same kind, when their forces and spherules are equal, otherwise they are of different kinds.

31. The degree of tendency of an atom or atoms to pass from one body or atom to another, is called the intensity of that body or atom.

32. Since the phenomena of the material world appear to indicate that there are two classes of atoms; those of one class being such as adhere and unite with great force, and add sensibly to the weight of bodies, while the others adhere with small force, and present no sensible gravity: and since by postulate second we are allowed to make this distinction, let the atoms of the first class be called *tenacious atoms*, and those of the other class *ethereal atoms*.

33. A collection of ethereal atoms enveloping a tenacious one is denominated its atmospherule.

Sch. Not only of the tenacious atoms, but also of the ethereal ones, there may be a great variety of sorts arising from small differences in their forces and in the extent of their spherules. The distinction between the two classes arises from a very great difference in their forces.

Axiom 1. Effects are proportional to their adequate causes.

2. Equal forces, acting on an atom in opposite directions, produce no change of state, but exactly counteract each other's effects.

3. Unequal forces acting in opposite directions produce a change of state, or new motion, in the direction of the greater force.

SECTION II.

Propositions respecting the Theoretical Constitution of Matter.

Proposition 1. If matter be constituted, as in *post.* 1., it will be capable of rest and motion, as will also the bodies consisting of such matter.

For since by (*post.* 1.) an atom of matter is constituted of forces equally diffused on all its sides, and is susceptible of the action of force; it will, if left to itself, or if acted on by equal opposite forces, remain in the same state in which it is put at first (*ax.* 2); but if acted on by unequal opposite forces, or by one single force, its original state will be changed (*ax.* 3.); therefore it is susceptible of all imaginable degrees of motion, and of rest, and since this applies to all atoms, it will be true of all bodies, which are composed of them.

Cor. A force impressed on an atom or body, and not counteracted by another force, produces a change of state in that body; this follows directly from *def.* 12. and this proposition.

Prop. 2. Matter constituted as in *post.* 1. cannot change its state, till it is acted on by some external force.

This is evident from the preceding proposition: or it may be shewn thus :

1. If an atom be at rest, it will remain in that state, since its constituent forces are equal on all its sides (*post.* 1. and *ax.* 2.)

2. If it be in motion it cannot of itself go out of the straight line in which it moves, because the forces are equal and opposite on both sides of that line, (*post.* 1. and *ax.* 2.)

3. It cannot move of itself with greater or less velocity; for the forces in the direction of its motion and in the opposite, as well as in all opposite directions are equal (*post.* 1. and *ax.* 2.)

Hence all atoms, and all bodies composed of them, are incapable of changing their present state, whether that be a state of rest, or of uniform motion in a straight line.

Cor. 1. Inertia is a property of matter thus constituted (*def.* 27.)

Cor. 2. The inertia of matter arises from the equilibrium of its constituent forces.

Cor. 3. Every change in the state of material beings, thus constituted, indicates the operation of some force.

Prop. 3. Matter constituted, as in *post.* 1., resists every change made in its state by any force impressed, and afterwards continues in the state into which it has been brought by the action of that force.

For since the constituent forces of every atom operate from the center at every point on all sides equally, (*post.* 1.) the impressed force will meet an opposite force from the center, on whatsoever side it is impressed, but equal opposite forces exactly counteract each other (*ax.* 2.): therefore to the impressed force there is a resistance, which having counteracted the impressed force, while that has changed the state of the atom, or body, a new state is attained, which will continue to be preserved, (*prop.* 2).

Cor. 1. Every atom and all bodies have a *vis inertiæ*, (*def.* 28.)

Cor. 2. The cause of the *vis inertiæ* of matter is the constituent forces of its atoms, for in that alone is the resisting force, or force to be overcome in order to produce a change of state in the atoms.

Cor. 3. Hence it is manifest, that the *vis inertiæ* is proportional to the absolute force of the atoms; or quantity of matter: for since the constituent forces are equally diffused on all sides of any atom (*post.* 1.) it will be, on any side or given part of a spherical surface, as the whole constituent forces of the atom, that is, (by *def.* 24. and *post* 1. *cor.* 2.) as the absolute force or quantity of matter.

Cor. 4. Hence to communicate a given velocity, to different atoms or bodies, will require a greater or less force, in proportion as the absolute force of the atom or body is greater or less, (*ax.* 1.)

Cor. 5. Hence also if atoms, or bodies, are continually changing their states, renewed impressions of force are continually applied.

Cor. 6. Atoms in many cases change continually, or tend to change the states of each other, but in other cases they tend to preserve each other in their present state: for if the center of one atom be in the expanse, or in the spherule of another, it will be under the continual impression of a force attractive or repulsive; but if it be in the common surface of the spherule and expanse, both its approach and separation will be opposed, (*post.* 1. and *def.* 22. and 23.)

Cor. 7. From this and proposition second, it appears, that the inertia of matter depends on the equilibrium of the constituent forces, and that the *vis inertiæ* depends on the quantity of the force. Hence if we could conceive

matter to be constituted of impenetrable extension alone, it would possess inertia, but not *vis inertiæ;* and the greatest body would be moved with the same freedom as the least.

PROP. 4. The motion, or change of motion, of any atom or body, produced at any instant, will be proportional to the force, which produced that change, and in the direction in which it acts.

For the equilibrium of the constituent forces is opposed, and therefore can be destroyed in that direction and proportion only; hence the proposition is manifest by *ax.* 1.

Cor. 1. If the atom or body were previously in motion, the new motion, after the action of the force, will be compounded of its former motion and the motion communicated.

Cor. 2. Hence if the body were moving in the direction of the force impressed, that motion will continue with the increase of that produced by the impressed force; but if it were moving in the opposite direction, it will be diminished by that new motion, and in other cases it will be compounded of the two motions, as shewn in mechanics.

Cor. 3. The velocity communicated to a given atom, or given body, is proportional to the force impressed.

For in this case the effect is evidently to be measured by the velocity produced. Or thus, conceive the force to be divided into any number of equal parts, and each part applied separately in the same direction, then these parts will produce equal increments of velocity in that direction, by this proposition and axiom first; hence the corollary is evident.

Cor. 4. Forces which communicate equal velocities are as the quantities of matter moved. For if the quantities of matter be any how increased or diminished, the resistance to motion is increased or diminished in the same

ratio, (*prop.* 3. *cor.* 3.) and therefore to produce the same velocity the force impressed must be increased or diminished in the same ratio.

Cor. 5. From the two preceding corollaries it appears, that the moving force, or momentum, varies as the quantity of matter and the velocity jointly.

Cor. 6. Hence the velocity varies as the force directly, and quantity of matter inversely; and the quantity of matter varies as the force directly, and velocity inversely.

Cor. 7. The force of an atom or body striking against a fixed material object, varies as the quantity of matter when the velocity is given, and as the velocity when the quantity of matter is given, and when neither is given, it varies in the compound ratio of both. For this striking force is the momentum of the moving body.

Prop. 5. The same things supposed, the action and re-action of atoms are equal and in opposite directions.

Since before the action, there was an equilibrium of the mass acted on, the re-action arises in consequence of the acting force, and is therefore an opposing force evidently in the opposite direction; and it cannot be greater than the acting force, since it operates against that action, only in consequence of the action itself; neither can it be less, for then the excess of the action would not act on the re-acting force, which is contrary to the hypothesis.

Cor. Hence, after the action of the force, the equilibrium remains, and before there can be any further change a new action and re-action must take place.

Prop. 6. The force of an atom acting on another, not in the surface of its spherule, varies as its absolute force directly, and the square of its distance inversely.

For in any spherical surface, whose center is that of the atom, the force in the whole surface is everywhere the same (by *post.* 1.) and therefore at any point in that surface it

is as the whole force in the surface, but the whole force is the same in every concentric surface of the atom (*post.* 1. *cor.* 1.); therefore, the force, at a given distance, is as the absolute force; and it is (*post.* 1.) inversely as the square of the distance, and hence the proposition is manifest.

Cor. 1. Let the circles about the centers A and B (*fig.* 1, 2, &c. *plate* I.) denote the extent of the sperules, and let the absolute force of A be m, and that of B, m', and their distance x; then the force of A on B is $\frac{m}{x^2}$, and that of B on A is $\frac{m'}{x^2}$; and $\frac{m+m'}{x^2}$ is the whole force, by which they tend to approach when situated as in *fig.* 1, and to recede when as in *fig.* 2; but when situated as in *fig.* 3, the spherules being equal, this force expresses their stability, because something more than $\frac{m+m'}{x^2}$ is necessary, either to separate them, or bring them nearer together.

Cor. 2. It is manifest that if the atoms were placed as in *fig.* 1, or 2, they would oscillate through a given space.

Cor. 3. When the atoms are placed as in *fig.* 3, the stability will be in the ratio compounded of the absolute forces directly, and the square of the radii inversely, and will therefore be greater as the absolute force is greater, and as the square of the radius is less.

Cor. 4. If the centers of several atoms be on the surface of the spherule of another, and if others again have their centers on the exterior sides of these, &c. various masses may be formed, of greater or less firmness, according to the absolute forces of the atoms, and the radii of their spherules, as appears from *cor.* 1, and 3: and the

variety becomes multiplied, when we admit of atoms of different radii and forces, in the constitution of the same body.

PROP. 7. Bodies, constituted as in the foregoing propositions, will have extension, figure, solidity, and divisibility, and will be capable of expansion and contraction.

From the nature of the atoms, as laid down in *post.* 1. it appears, that a finite force cannot make their centers coincide: and hence when put together, as noticed in *prop.* 6. *cor.* 4. or otherwise collected, they will form bodies having extension, terminated at the surfaces of the exterior spherules, which gives them a certain figure, according to the situation and order of the atoms. Also the increasing resistance, as the centers, by the application of force, are brought nearer to each other, will manifest their solidity. And since the atoms are held together by a finite force, they may by a superior force be separated, and bodies are thus divisible. Again, from all this it is seen that the aggregates thus formed, are capable of expansion and contraction.

PROP. 8. To determine the relative motions and other circumstances of two atoms left to their mutual actions.

Let A and B, (*fig.* 3, 4, &c.) be two atoms, r and r' the radii of their spherules (r being not less than r'), m and m' their absolute forces, a their distance at first, x any other distance, s the whole space passed through by both, v the velocity by which they approach or recede at the distance x.

Then $\frac{m}{x^2}$ is equal to the force of the atom A on B, and $\frac{m'}{x^2}$ is equal to that of B on A, therefore $\frac{m+m'}{x^2}$ is the whole force, when both are attractive, or both repulsive, and $\frac{m \backsim m'}{x^2}$ when one is attractive, and the

other repulsive, and $s = a \backsim x$: Hence $v\,d\,v = \frac{m \underset{\backsim}{+} m'}{x^2}\,d\,s$ (Mech.), and $v^2 = 2(m \underset{\backsim}{+} m')\,\frac{a \backsim x}{a\,x}$, or $v = \left\{2(m \underset{\backsim}{+} m')\,\frac{a \backsim x}{a\,x}\right\}^{\frac{1}{2}}$. Also as $m \underset{\backsim}{+} m' : m :: v$: velocity of B $= \left(\frac{2\,m_{2}}{m \underset{\backsim}{+} m'} \cdot \frac{a \backsim x}{a\,x}\right)^{\frac{1}{2}}$; in like manner the velocity of A $= \left(\frac{2\,m'^2}{m \underset{\backsim}{+} m'} \cdot \frac{a \backsim x}{a\,x}\right)^{\frac{1}{2}}$; and therefore the velocity of A : velocity of B :: $m' : m$, which may otherwise be easily determined. Hence the space described by A : space described B :: $m' : m$. Several cases will occur according to the situations, radii, and forces, of the atoms.

While x is greater than r the force is wholly attractive, *fig.* 4; when less than r' it is wholly repulsive, *fig.* 8. In *fig.* 6, A repels, and B attracts. Hence when the atoms are placed in the situation represented by *fig.* 4, they will approach, and the motion will be accelerated till they attain the position *fig.* 5, it is then accelerated, uniform, or retarded, according as m' is greater, equal to, or less than m, till it attains the situation *fig.* 7: it is then continually retarded, till it is wholly destroyed, as at *fig.* 8, where the motion commences and continues in the opposite direction, till the atoms attain their first situation, and thus they will continue to oscillate: for the motion generated, while the force is attractive, will be destroyed while it is repulsive, and after that it will be regenerated, and conversely. Also always the velocity of A, is to the velocity of B, as m' to m, and therefore the velocity of each is always the same, while passing the same point, when it is advancing or receding, and all the oscillations are performed in the same time.

When the radii of the spherules are equal, and placed

at first as in *fig.* 3, the atoms will remain in that situation, and be retained in it by the force $\frac{m+m'}{r^2}$, since it will require a greater force than this, either to bring them nearer together, or to produce a separation.

If the radii are unequal, r being greater than r'; then the atoms will remain at rest, if $m = m'$, and they are placed at first in any of the positions *fig.* 5, 6, and 7, but the least force, if placed as at *fig.* 6, will move them either way; at *fig.* 5, the least force will make them approach, but it will require a force greater than $\frac{m+m'}{r^2}$, or $\frac{2\,m}{r^2}$ to separate them; and at *fig.* 7 the least force will cause them to recede, but a force greater than $\frac{2\,m}{r'^2}$ will be required to bring them nearer together.

If m be greater than m', they will rest only when placed in the situation *fig.* 5, and the force requisite to separate them must exceed $\frac{m+m'}{r^2}$, and to bring them nearer it must exceed $\frac{m-m'}{r^2}$; if m' be greater than m, they can rest only when placed as at *fig.* 7, where their separation is opposed by the force $\frac{m'-m}{r'^2}$, and their approach by $\frac{m'+m}{r'^2}$.

When the two atoms are left to their mutual actions, and consequently oscillate through a given space; let a be their greatest, and a' their least distance. Then while the atoms are approaching each other, it follows that (1) The velocity acquired in passing from the distance a to that of r is $\left\{2\,(m+m')\,\frac{a-r}{ar}\right\}^{\frac{1}{2}}$. (2) The velocity acquired, or lost from the distance r to that of

r', is $\left\{2\,(m \backsim m')\,\frac{r-r'}{rr'}\right\}^{\frac{1}{2}}$ (3) The velocity lost in the distance from r' to that of a' is $\left\{2\,(m+m')\,\frac{r'-a'}{r'a'}\right\}^{\frac{1}{2}}$. The second part evidently vanishes when $m = m'$, or $r = r'$, the velocity remaining constant, when $m = m'$, and the space being nothing when $r = r'$.

Also when m' is greater than m, the velocity increases in this part, and decreases when m is greater than m'; and in this case the third part will be positive, or negative, or it will vanish, according as the velocity lost in the second part is less, or greater than, or equal to that acquired in the first part.

And since the velocity is all destroyed at the distance a', we have by the hypothesis $\left\{(m + m')\,\frac{a-r}{a\,r} + (m'-m)\,\frac{r-r'}{rr'} - (m+m')\,\frac{r-a'}{r'\,a'}\right\}^{\frac{1}{2}} = 0$

Therefore $a = \dfrac{r\,r'\,a'}{2\,a'.\,\frac{m\,r' + m'\,r}{m + m'} - rr'}$, and

$a' = \dfrac{r\,r'\,a}{2\,a.\,\frac{m\,r' + m'r}{m + m'} - rr'}$, If $m = m'$

$a = \dfrac{r\,r'\,a'}{a'\,r' + a'\,r + r\,r'}$ and $a' = \dfrac{r\,r'\,a}{a\,r' + a\,r - r\,r'}$

and if $r = r'$, $a = \dfrac{r\,a'}{2\,a'-r}$ and $a' = \dfrac{r\,a}{2a-r}$.

Cor. 1. If three or more atoms be placed in the same straight line at certain distances, they will vibrate in that line according to the circumstances of the situations, force, and radii of the atoms.

Cor. 2. If they are not placed in a straight line, they will still vibrate according to the circumstances, and if oblique

motions be communicated to some of them, it is evident that certain revolutions will be performed, subject to the laws which govern the motions of the planets.

Cor. 3. But when the centers of the atoms are placed in the surfaces of the spherules of each other, they will form bodies, more or less compact and firm, according to their forces and radii.

PROP. 9. Let there be any number of atoms A, B, C, &c. (*fig.* 9) whose forces and radii are equal, and whose centers are in a straight line, each in the surface of the spherule of the next, then the force which supports or opposes the permanency of any two adjacent atoms in their places, will be expressed by the following series, *viz.*

$$\frac{2m}{r^2}\left\{1 \pm \left(\frac{1}{2}+\frac{1}{3}\cdots\cdots\frac{1}{s}+\frac{s}{(s+1)^2}+\frac{s}{(s+2)^2}\cdots\cdots\frac{s}{(n-s)^2}+\frac{s-1}{\{n-(s-1)\}^2}\cdots\frac{1}{(n-1)^2}\right\}, \quad (\mathrm{A})$$

the positive sign being used, when we express the force tending to prevent their separation, and the negative sign when the force tending to prevent, or cause their approach, is expressed; the atoms, on the opposite sides of the adjacent ones in question, being kept in their relative situations, by a force which has no other effect: n being the whole number of atoms; s, the number to the nearest of the two whose permanency is sought, that is, for the first and second, $s = 1$, for the second and third, $s = 2$, &c., r being the radius of each spherule, and m its absolute force.

First, When A and B are the adjacent atoms, or $s = 1$, we have,

$$\frac{2m}{r^2} + \frac{2m}{r^2}\left\{\frac{1}{4}+\frac{1}{9}\cdots\cdots\frac{1}{(n-2)^2}+\frac{1}{(n-1)^2}\right\} \quad (1).$$

$\frac{2m}{r^2}$ is the force tending to prevent the separation or

access of A and B; and the sum of the following terms is the force tending to oppose their separation, and to favour their approach, which is evident from *prop.* 6, and the law of the force.

Secondly, When the adjacent atoms are B and C, $s = 2$, when they are C and D, $s = 3$, &c., and we have

$$\frac{2m}{r^2} \pm \frac{2m}{r^2} \left\{ \begin{array}{l} \frac{1}{4}+\frac{1}{9}+\frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2}+\frac{1}{(n-2)^2} \\ \frac{1}{4}+\frac{1}{9}+\frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2}+\frac{1}{(n-2)^2}+\frac{1}{(n-1)^2} \end{array} \right\} (2)$$

$$\frac{2m}{r^2} \pm \frac{2m}{r^2} \left\{ \begin{array}{l} \frac{1}{4}+\frac{1}{9}+\frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2} \\ \frac{1}{4}+\frac{1}{9}+\frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2}+\frac{1}{(n-2)^2} \\ \quad \frac{1}{9}+\frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2}+\frac{1}{(n-2)^2}+\frac{1}{(n-1)^2}, \end{array} \right\} (3)$$

$$\frac{2m}{r^2} \pm \frac{2m}{r^2} \left\{ \begin{array}{l} \frac{1}{4}+\frac{1}{9}+\frac{1}{16} \cdots\cdots \\ \frac{1}{4}+\frac{1}{9}+\frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2} \\ \quad \frac{1}{9}+\frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2}+\frac{1}{(n-2)^2} \\ \qquad \frac{1}{16} \cdots\cdots \frac{1}{(n-3)^2}+\frac{1}{(n-2)^2}+\frac{1}{(n-1)^2} \end{array} \right\} (4)$$

&c.

From which by addition we easily collect the series (A) and the law of its continuation.

Cor. 1. If the number n of the atoms do not exceed six, the supposed restraining force is unnecessary, for the system will remain at rest when the atoms are left to their mutual actions, because in this case the two middle atoms are pressed by the force $\frac{599}{600} \times \frac{2m}{r^2}$, but their approach is opposed by the force $\frac{2m}{r^2}$; also their separa-

tion is opposed by $\frac{2m}{r^2} \times \frac{1199}{600}$, hence they will not separate.

Cor. 2. When n exceeds six, the force between the third and fourth to bring them nearer is greater than $\frac{2m}{r^2}$, the force which opposes their approach; and when n is still greater, that force is increased while the opposite force $\frac{2m}{r^2}$ remains the same; hence when n is more than six, and the supposed restraining force is removed, so that the atoms are left to their mutual actions alone, they will be brought nearer together, and this circumstance will increase the pressure of the whole, the one towards another, so that an equilibrium will be attained only, when the increased resistance of contiguous atoms becomes an exact counterpoise to the attractions by which they adhere. In this state a small force exerted either way will destroy the equilibrium, while they are approaching, the resistance increases indefinitely, while separating, the resistance increases to its maximum, and then decreases indefinitely.

Cor. 3. It is manifest, that the pressure on the atoms is greater as they are nearer to the center of the row.

Cor. 4. When n is a very large number, the pressure between every two atoms, near the center, is nearly the same. For in this case, the action of the atoms towards the extremities of the row, on the central ones, is small.

Cor. 5. If several such rows be placed together, the pressure will be increased by the oblique action of the additional rows, and hence they will be brought nearer together by means of that action.

Cor. 6. If we suppose a corpuscle or body to be constituted of such atoms, the atoms about the central parts will be pressed together by nearly the same force.

Cor. 7. If a rod of matter, so composed, were made to support a weight, the rod would stretch, and yet would become stronger till it reached a maximum, after which, a small additional force would break the rod.

Cor. 8. The adhesive force will be greater as the absolute force is greater, and the radii of the spherules is less.

Cor. 9. Hence, if the absolute forces, and the radii of the spherules be given, it is easy to conceive, that the forces may be so increased, and the radii diminished, that the adhesion at its maximum shall exceed a given quantity.

Prop. 10. Let seven atoms whose forces and radii are equal, be equidistant, having the center of each in the surface of the others as in *figs.* 10 and 11; they will remain in a state of equilibrium.

For the centers of six of them, being in the angular points of a regular hexagon, we have $b\,c = a\,b$, and $b\,d = a\,b\sqrt{3}$, and taking the force of each at the distance $a\,b$ equal to m, we shall have at the distance $b\,d$ the force equal to $\frac{m}{3}$, and at $e\,b$ it is $\frac{m}{4}$, also (by Mech.) the effects of the first of these, in the direction $b\,a$, must be diminished in the ratio of $b\,c$ to $b\,n$, and of the other, in that of $b\,d$ to $b\,m$. Hence, the whole force of the six atoms on the seventh at b, in the direction $b\,a$, is, $2\,m + 2\,m + \frac{2\,m\sqrt{3}}{3} + \frac{m}{2} = \left(\frac{9}{2} + \frac{2\sqrt{3}}{3}\right) m$, which force opposes the separation of any one from the center, the others being kept in their places. Again the forces of d, f, and e favour, but those of a, c, and g, oppose the access of b towards the center. Hence we have on the whole $4\,m - \frac{2m\sqrt{3}}{3} - \frac{m}{2} = \left(\frac{7}{2} - \frac{2\sqrt{3}}{3}\right) m$, which

is a positive quantity, opposing any contraction in the system, and therefore the equilibrium is sustained.

Cor. 1. If the central atom were removed the equilibrium would still remain. For in this case, the force preventing their separation is $\left(\frac{5}{2} + \frac{2\sqrt{3}}{3}\right) m$, and that preventing their access is $\left(\frac{3}{2} - \frac{2\sqrt{3}}{3}\right) m$, both of which are positive quantities. Hence also if the force of the central atom were less or greater, the stability would continue, being diminished in the first case, and increased in the second; thus if the force of the central atom be $a\,m$, the others remaining as before, the force opposing separation is $\left(\frac{7}{2} + a + \frac{2\sqrt{3}}{3}\right) m$, and that opposing the access is $\left(\frac{5}{2} + a - \frac{2\sqrt{3}}{3}\right) m$.

Cor. 2. Hence it follows, that if the force of the central atom be indefinitely greater than that of the others, the force, necessary to alter their distance from the center, is indefinitely greater than that requisite to alter their distances from each other, when the central atom is removed.

Cor. 3. Let the force of the central atom be $a\,m$, and its spherule greater than that of the others as a in *fig.* 12, then the force opposing contraction in the system, is $\left(\frac{5}{2} + a - \frac{2\sqrt{3}}{3}\right) m$, as in *cor.* 1, and that opposing expansion is $\left(\frac{3}{2} - a + \frac{2\sqrt{3}}{3}\right) m$, the force between a and b, *viz.* $(1 + a)\,m$ being now repulsive. Hence while a does not exceed $\frac{3}{2} + \frac{2\sqrt{3}}{3}$, or 2·655 nearly, the equilibrium will remain, but if a exceed this number, an expansion will take place.

Cor. 4. Next let the spherule of the central atom be less than the others, as *c* in *fig.* 12, the rest being as before; then as in *cor.* 1. the expansion is opposed by the force $\left(\frac{7}{2} + a + \frac{2\sqrt{3}}{3}\right)m$; but the contraction only by $\left(\frac{1}{2} - a - \frac{2\sqrt{3}}{3}\right)m$, because now the force between *a* and *b*, *viz.* $(1 + a)\, m$ is attractive; but this is negative whatever is the real value of *a*, hence in this case a contraction will always ensue, till they are in the situation where the resistance will produce an equilibrium.

Cor. 5. If the absolute force of the central atom be indefinitely greater than that of the others, whatever may be its radius, it will retain a great number of the others on the surface of its spherule as *b*, *c*, *d*, &c. in the section shewn in *fig.* 13. This is evident from *cor.* 2 and 4. This shews that a tenacious atom will sustain many ethereal ones on its surface.

Cor. 6. The same things being supposed as in the last *cor.* and the number of ethereal atoms, *b*, *c*, *d*, &c. do not exceed a certain quantity, depending chiefly on the forces of the atoms, then another ethereal atom *p*, placed near them, will be attracted to the surface of *a*. For the force of *a* acting on *p* will produce a pressure on *c* and *d*, tending to separate them, and as the resistance of these, while their centers are sufficiently distant, is indefinitely small in comparison of the force of *a*, the center of *p* will be brought to the surface of the spherule of *a*, between *c* and *d*. Hence the centers of the other atoms will be nearer each other, and another atom would be introduced with somewhat more difficulty, and by continuing the process, so large a number of atoms may be conceived to be brought unto the surface of the spherule of *a*, and their centers crowded so near together, that they shall present

a resistance sufficient to prevent the introduction of others in the same way, so that if other ethereal atoms be placed near them they will rest on the outward surfaces of the stratum already introduced.

Cor. 7. The whole surface of the spherule being enveloped by other atoms, as in the last *cor.* over this stratum other strata may be easily conceived to be placed, constituting a sort of small atmosphere, which we may call an atmospherule, retained by the powerful action of that which occupies the center; each of those in the second stratum resting on three adjoining ones of the first, and similarly of the others. Such an atmospherule is represented in *fig.* 14, the dots being designed to denote the centers of ethereal atoms.

Cor. 8. Two or more atoms, forming a particle, may have the same atmospherule, also, since different sorts of ethereal atoms are admitted, this will hold, when each of the tenacious atoms, has its own atmospherule of one or more kinds, and the whole surrounded by those of another kind: and it is evident that the first sort of particles will be more fixed and permanent than the others.

Cor. 9. If a large collection of ethereal atoms be contained in a given space, and if two or more tenacious atoms be put into this space, they will collect atmospherules, and if removed, that which has the greatest absolute force and the least spherule will bring off a more extensive and more dense atmospherule than the other.

Cor. 10. It is manifest that, when an atom contains a large atmospherule, the centers of the ethereal atoms are within the spheres of each other's repulsion, so that if they were freed from the action of the central tenacious atom they would recede from each other with great velocity.

PROP. 11. The ethereal atoms, forming a stratum on

the surface of a tenacious one, when in equilibrium among themselves, will be uniformly and symmetrically arranged. For otherwise the repulsions between some of them as *n* and *o* (*fig.* 14.) and that between others as *m* and *o* in the same stratum would be different, and motion would ensue, which is contrary to the hypothesis. In this figure the centers of the ethereal atoms, and not their spherules, are represented by the dots.

Cor. 1. Hence the atmospherules in every part of a spherical surface, whose center is A (*fig.* 14.), is of the same density, when not affected by external causes.

Cor. 2. When a second stratum of ethereal atoms is no more than just supported in equilibrium on the first; and if in that case one or more strata be placed over these, some additional atoms will be brought into the first stratum. For the equilibrium will now be destroyed by the pressure of the atoms introduced.

Cor. 3. When an atmospherule is increased, it will be not only more extended, but also its density at the same distance from the center A (*fig.* 14.) will be augmented.

Cor. 4. If the atmospherules consist of two sorts of ethereal atoms, that sort which has the greater absolute force, and the less spherule will occupy chiefly the lowest part of the atmospherule.

Prop. 12. If an ethereal atom be brought into a stratum of an atmospherule, by an extraneous force, it will be retained there even if that force be removed.

For let *d* (*fig.* 15,) be the atom resting on three others *a*, *b*, and *c*, in one stratum or spherical surface of a tenacious atom, whose center is A, and let *d* be forced down to *n*, in the same spherical surface in which are *a*, *b*, and *c*; it will be retained in that position, because its tendency to rise in A *d*, is indefinitely small and it is kept down by the definite action of the tenacious atom A; also the

repulsive forces of the spherules on which it is incumbent, prevents its depression.

Cor. The atmospherule of an atom will be spherical, while not affected by extraneous matter, but that of a particle will differ from a sphere more or less according to the number, force, radii, and position of the atoms, which compose the particle; yet evidently there will be a proportionate degree of uniformity, and in general there will be a tendency to the spheroidal form.

LEMMA 1. Let the forces vary inversely as the square of the distance; the centers of force A and B, (*fig.* 16); the absolute force of A $= a\ m$, and that of B $= m$; it is required to find the locus of the line where the forces are equal. Let x and y be the co-ordinates of C, having the point A for their origin, and AB $= b$, then we have $\frac{m\ a}{AC^2} = \frac{m}{BC^2}$, or $BC^2 = \frac{1}{a} \times AC^2$, and $AC^2 - x^2 = BC^2 - (b \backsim x)^2$; therefore $AC^2 = x^2 + y^2 = \{x^2 - (b \backsim x)^2\} \frac{a}{a-1}$, or $y^2 + \left(x - \frac{a\ b}{a-1}\right)^2 = \frac{a\ b^2}{(a-1)^2}$, which is the equation to the circle, whose radius is PO $= \frac{b \sqrt{a}}{a-1}$, and center in AB, at O, AO $= \frac{a\ b}{a-1}$. Also $y = o$, gives AP $= \frac{b \sqrt{a}}{\sqrt{a}+1}$, and AF $= \frac{b \sqrt{a}}{\sqrt{a}-1}$, hence BP $= \frac{b}{\sqrt{a}+1}$, and BO $= \frac{b}{a-1}$.

Cor. 1. If $a = 1$, PQ becomes a straight line P′Q′, bisecting AB at right angles, for in this case PO is infinite and AP$=\frac{b}{2}$.

Cor. 2. If an atom were placed any where in PCQ, it would begin to move in a line bisecting the angle ACB, that is in the chord of the arc CP, when both A and B

are attractive or repulsive; but it would begin to move in a line perpendicular to the bisecting line, when one is attractive and the other repulsive, that is in the chord CF.

Cor. 3. If an atom be placed within the circle PCQ, it will be acted on with greater force by B than by A, and the contrary if it be without the circle.

For let A, P and B, (*fig.* 17) be as in the last figure, and G a point within the circle; draw the chord PGC, and join AC, CB, AG, and GB, make CH equal to CB and join HG.

Then CP bisects the angle ACB (E. 3. 6.) hence it bisects HGB, and the line which bisects the angle AGB falls between P and B, therefore the ratio of AG to GB, is greater than that of AP to PB, or AC to CB; therefore $\frac{m}{BG^2}$ is greater than $\frac{ma}{AG^2}$ that is the force toward B, at G, is greater than that towards A: in the same way, it may be shewn, that the force is less towards B, than towards A, when G is without the circle.

Cor. 4. The circle or locus of equal force is concave towards that center, where the absolute force is the less of the two; and its nearer parts are convex towards the greater force.

Cor. 5. The nearer the centers A and B are to each other, the less is the circle of equal force: for the radius $\frac{b\sqrt{a}}{a-1}$ is evidently in the direct simple ratio of the distance (b) between them, the absolute forces being given.

Cor. 6. It is also manifest, that the radius OP will be diminished, by a diminution of the force at B, the distance C, and the force at A, remaining the same.

Cor. 7. If PCQ were to revolve on the axis PF, the surface of the sphere generated by PCQ would be the locus of equal attraction of the atoms.

Cor. 8. It may be further observed, that if a be indefinitely great, and positive, the center O is indefinitely near to B, on the right, but when it indefinitely great, and negative, the center O is indefinitely near to A on the left.

Lemma 2. If A, C, and B (*fig.* 18) be the equidistant centers of three atoms A, B and C, fixed in their places, it is required to resolve the forces of these on an atom at D, within the spherule of A or B; into two forces in the directions of DC, and DG perpendicular to DC, the absolute forces of A and B being each $= m$ and that of C $= am$.

Let the angle at C be called θ, then $\sin \text{CDB} = \frac{\text{AC} \sin \theta}{\text{DB}}$, and $\sin \text{ADC} = \frac{\text{AC} \sin \theta}{\text{AD}}$.

Therefore the force perpendicular to CD is $\frac{m\text{AC}}{\text{DB}^2}$ $\sin \theta \mp \frac{m\text{AC}}{\text{DA}^2} \sin \theta$. (A)

And the force in DC is, $\frac{ma}{\text{DC}^2} - \frac{m}{\text{DB}^2} . \cos \text{CDB} \mp \frac{m}{\text{DA}^2} . \cos \text{CDA} = \frac{ma}{\text{DC}^2} - \frac{m}{\text{DB}^3} (\text{DB}^2 - \text{AC}^2 \sin^2 \theta)^{\frac{1}{2}}$ $\mp \frac{m}{\text{DA}^3} (\text{DA}^2 - \text{AC}^2 \sin^2 \theta)^{\frac{1}{2}}$. (B)

The negative sign of the last terms, in A and B, being used when D is within the common part of the spherules of A and B, the directions DC and DG being considered positive: if D were within the spherule of C, $\frac{ma}{\text{DC}^2}$ would be negative.

Cor. 1. When θ is 90° the force in DG vanishes, since it consists of two parts equal and opposite: and the force in DC becomes $\frac{ma}{\text{DC}^2} - \frac{2m\,\text{DC}}{\text{DB}^3}$. Hence for the point

of equilibrium in CE, we have $a = \frac{2\,DC^3}{DB^4}$, which shews that the equilibrium cannot exist if a be not less than 2, and the atom D will descend to O, in the surface of the spherule C.

Cor. 2. When $\theta = O$, the force in DG vanishes, and that in DC becomes $\frac{ma}{DC^2} - \frac{m}{DB^2} + \frac{m}{DA^2}$; and for the point of equilibrium in BF, we have $a = DC^2 \left(\frac{1}{DB^2} - \frac{1}{DA^2}\right) = \frac{4\,DC^3 \quad AC}{(DC^2 - AC^2)^2}$. If $DC = \frac{n}{r}$, and $AC = 1$, then $a = \frac{4\,m^3\,r}{(m^2 - r^2)^2}$. DC being taken, $\frac{3}{2}$, $\frac{4}{3}$, &c. we have the corresponding values of $a = 8\frac{16}{25}$, $15\frac{33}{49}$, &c.

Cor. 3. If only C and B were acting on D, the tangential force in DG becomes $\frac{m\,AC \sin\theta}{DB^3}$; and the force in DC is $\frac{ma}{DC^2} - \frac{m}{DB^3}(DB^2 - AC.^2 \sin^2\theta)^{\frac{1}{2}}$. And in this case when $\theta = 90°$, the force in DG is a maximum, and $= \frac{m\,AC}{DB^3}$, and the force in DC is $\frac{ma}{DC^2} - \frac{m\,DC}{DB^3}$. Also when $\theta = O$, the force in DC vanishes, and that in DC becomes $\frac{m\,a}{DC^2} - \frac{m}{DB^2}$. Hence for the equilibrium in BF we have, $a = \frac{DC^2}{DB^2} = \frac{DC^2}{DC^2 - CB^2}$; and therefore the equilibrium cannot exist unless a is greater than unity, that is when the absolute force of C is not greater than that of B, the atom will not rest within the spherule of B in BF.

Cor. 4. If the absolute forces of A and B had been unequal, or if there had been more forces acting on D, they

might similarly have been resolved into the two directions DC and DG.

Obs. In the 19th, 20th, &c. figures, where dots are placed around a circle, the dots are intended to represent the centers of ethereal atoms, and the circles, are to denote the extent of the spherules of the tenacious ones; the extent of the spherules of the ethereal atoms may be supposed to be greater or less than these, they are omitted in order to avoid confusion in the figures.

Prop. 13. The atmospherules of two atoms, fixed in their places, and situated at such a distance, that the atoms of the one cannot act on those of the other by repulsion, will be elongated in the line which joins their centers, and will be most accumulated on the sides between the centers. The same is also true of two particles allowing for some variation in the effect occasioned by the situation and difference of their component atoms.

This proposition is manifest from the first lemma, and the law of the force, for the action of A, (*fig.* 19.) will diminish the tendency of the ethereal atoms, on the side E, towards B, and will increase that of the atoms, on the side F, towards B, and the effects of the actions of B, on the atmospherule of A, will be similar; hence the atmospherules will be extended as in the figure, more or less, according to the situations and forces of A, and B.

Cor. An ethereal atom, placed any where between A and the line PQ, will fall into the atmospherule of A, and if placed between B and PQ, it will fall into that of B, which is evident from *lem.* 1. *cor.* 3.

Prop. 14. When two atoms A and B, (*fig.* 20.) are placed so near together, that their atmospherules repel each other as at D, E, the atmospherules will be depressed at the sides D, E, and extended on the opposite

sides G and F, as in the figure; and the like will hold of two particles.

For the repulsion between the ethereal atoms, situated on the sides, D, E, will cause them to recede, and flow to the opposite parts, hence when an equilibrium is attained, the atmospherules will be most extended towards G, and F; and there will be a tendency in their mutual actions, to preserve the atmospherules distinct and separate, or to cause them to become so; since the ethereal atoms of each are more attracted by their own central atom or particle than by that of the other.

Cor. 1. The density of the atmospherules, at the same distance from the center, will evidently be encreased.

Cor. 2. The nearer together the atoms or particles A and B are placed, the greater will be the alteration in the figure of the atmospherules, and the density at the same distance from the center A or B will be the greater.

Cor. 3. Let PQ be the line of equal attraction between A and B. Now if an additional quantity of ethereal atoms be presented to one of the atmospherules, as suppose to that of A, it will be extended, and will approach nearer to PQ, and that of B will recede from PQ, and both will be more extended on the opposite sides, as at G and F; also, at the same distance from the centers, the density of both will be encreased.

Cor. 4. The centers A and B of the tenacious atoms being kept fixed in their places, if the quantity of ethereal atoms added to A be sufficient to cause its atmospherule to extend beyond PQ, by depressing that of B, part of that extended atmospherule will pass or slide over to the other, because that part is more attracted by B, than by A, and this transfer of the atoms will be more or less energetic, according to the difference in the quantity passing over, and in the force of the tenacious atoms, also

by this transfer a state of vibration will be produced in the atmospherules.

Cor. 5. A similar effect would evidently take place, if, instead of an additional portion of ethereal atoms, a sufficient pressure were applied to the atmospherule of A, directed from the parts at G, towards B.

Cor. 6. If instead of adding to the atmospherule of A, a part of that of B were removed, similar effects would be produced, but in this case the density at equal distances would be diminished.

Cor. 7. If while ethereal atoms are added to A, a proportional quantity were also added to B, the transfer would be prevented, and the atmospherules would be still more extended towards G and F, or, if while ethereal atoms are communicated to A, a sufficient force were applied at F, to counteract the extension of the atmospherule, the transfer would still be prevented.

Cor. 8. When the proportionate quantity of ethereal atoms is such, that a transfer is just about to take place, a slight agitation would cause a body of ethereal atoms to pass from the one to the other, after which they would be restored again to a state of equilibrium, and form distinct atmospherules.

Cor. 9. When a transfer is made of part of one atmospherule to that of another, as from A to B, a repulsion will take place between the two atoms or particles, which if at liberty, or free to move, will consequently recede from each other. For it is evident that there is a repulsion between the ethereal atoms passing over PQ from D, and those which fall in to supply their place, and restore the equilibrium; and also between the same atoms and those at E, when they meet the atmospherule of B; hence on both accounts there is a tendency to separate A and B, causing them to recede.

Cor. 10. In the case of two particles, it is evident, that the relative situations of the tenacious atoms themselves will be affected by the mutual actions, while the atmospherules are altered, or when a transfer is made.

Cor. 11. If particles of different kinds be placed near each other, a transfer in some cases may be made from one to the other, when under like circumstances it would not have been made, had like particles of either kind been presented to each other. Again in other cases the particles of different kinds may hold their atmospherules with such force that a transfer from the one to the other will not be effected, but by a much greater increase in the atmospherule of one of them.

Prop. 15. If two tenacious atoms A and B (*fig*. 21.) with their atmospherules be placed very near each other, the ethereal atoms will recede more or less from the parts between A and B, till in certain cases, and at certain distances, both will become enveloped in one atmospherule.

For the repulsion of the ethereal atoms between A and B will cause the recession, and if they be forced sufficiently near, the atmospherules will at length intermix, and form one atmospherule; hence an union of the tenacious atoms will ensue, varying in its stability according to the circumstances of their distance, and the forces and magnitudes of their spherules.

Cor. 1. The actions of the ethereal atoms, although in some cases tending to preserve; will in many cases tend to separate the tenacious ones, and the more so as the atmospherules are increased.

For in the case of equal atoms, having equal spherules, as in *fig*. 21 and 22, it is easily seen, that the resultant of the forces of A and B, on the ethereal atoms, in the line of equilibrium QPR, and on both sides of it, tends to press them on the convex sides of A and B, opposing their ap-

proach, and the more so as the atmospherules are the more extended: similar effects will likewise take place when the forces of A and B are unequal, as in *figs*. 23 and 24, where the absolute force of A is represented as greater than that of B; and in *figs*. 25 and 26, where the spherules of A and B are also unequal, and the force of A greater than that of B, as shewn by the line of equilibrium PQ or PR.

Cor. 2. The nearer together the tenacious atoms are placed, when involved in one atmospherule, the less effect will the atmospherule have in opposing their cohesion; but this will be greatly modified by the difference of the forces, and the extent of the spherules.

For it is seen that the actions of A and B on the ethereal atoms in *fig*. 22, about the line R Q, are much less than in *fig*. 21, and consequently the re-actions are less between the spherules of A and B; and also these actions are more oblique to the line connecting the centers, hence on both accounts they will have less effect in diminishing the cohesion; much more will this difference appear in the case of atoms, of unequal force as in *figs*. 23 and 24, and also in *figs*. 25 and 26.

Cor. 3. The distance between the tenacious atoms may be so great, that the atmospherules shall prevent the approach of A and B, and even cause them to recede, while under a pressure not exceeding a given limit.

Cor. 4. If two tenacious atoms be under circumstances, in which the common atmospherule cannot separate them (*i. e.* destroy their cohesion) they will form a particle, having a kind of polarity, that is, their attraction will be stronger on some sides than on others; and the polarity will be more or less effective and distinct, according to the difference of the forces and spherules of the two component atoms.

Cor. 5. When the atoms are of the same kind, as in

figs. 21, and 22, and situated in a collection of such atoms contained in a certain space, they will be equally affected by an addition of ethereal matter, and by pressure tending to reduce the space occupied, hence they will not easily unite, till by the abstraction of ethereal atoms, or increase of pressure, or both, they are capable of taking the solid or liquid form.

Cor. 6. When the force of one atom is less, as B, *figs.* 23 and 24, and especially when the spherule of the weaker atom B is larger than the other, as in *figs.* 25 and 26, the tendency to combine will be greater: for the action of A, independently of the pressure, will bring a portion of the ethereal atoms within the spherule of B; hence the atmospherules will readily intermix, and the combination will be formed with greater or less facility, according to the ratio of their radii and of their forces.

Cor. 7. If that atom, which has the greater force, has also the greater spherule, the tendency to combination and to firmness of union will pass through various gradations to a minimum, on both sides of that particular relation in which the atoms at the surfaces are equal; that is, in which the squares of the radii of the spherules are directly as the forces.

PROP. 16. If three tenacious atoms, with their atmospherules, are placed sufficiently near to each other, they will become enveloped in one atmospherule, and will form a particle.

This is evident from the last proposition and its corollaries.

Cor. 1. If two of the atoms B and C, (*figs.* 27, 28, &c.) be of one kind, and the other A of a different kind; then will the natural position of the three atoms be as in *figs.* 27, 28, and 29; for when the three are left to their own mutual actions, the most firm, and natural arrangement

would be similar to that of *fig*. 31, now conceive the atmospherules, and also pressure to be applied; then the actions of A, B and C, on the ethereal matter will conspire with the pressure to cause a separation of B and C, as far as it respects the actions near *a* and *c*, and the separation taking place, it is evident that B and C must revolve on the center *c*, till *d*, and *b* are in a straight line with *c*, as at *e* and *f*, taking the positions of *figs*. 27, 28 and 29, in which the equilibrium is formed.

Similar reasoning will apply to *fig*. 30, but here the centers of B and C will move on the surface of A, till the equilibrium is attained, hence when three atoms combine these forms will result.

Cor. 2. In such combinations very great differences in the facility of union, and consequently stability, will arise from the degree and relation of the forces, and also from the different magnitudes of the spherules: Thus if A, B, and C be all atoms of great force, and nearly of the same force at their surfaces, the ethereal matter will not in this case fall within C and B, and must be supposed to be only on the exterior sides.

This combination will be feeble, and not easily formed, because the actions at *m* and *n*, combined with the pressure, will tend greatly to separate them, so that if the union take place at all, a moderate increase of ethereal matter, and pressure, will cause a disunion, and often with explosion when many atoms at once are thus affected. But if A have a great force, compared with that of B and C, the union will not be easily destroyed, especially if the weaker atoms, B and C, have the greater spherules, as represented in the *figs*. 27, 28, and 29, for in this case a larger portion of ethereal matter will be brought within the spherules of B and C, as in *fig*. 29, and those portions, which rest on the convex sides of A, counteract each

other, and tend to strengthen the combination, which will therefore be much stronger than a similar combination of two atoms only.

Sch. This condition seems to indicate, that steam is constituted of one atom oxygen, and two hydrogen, and that the spherule of hydrogen is greater than that of oxygen.

Cor. 3. Hence, in a mixture of two sorts of atoms with their atmospherules, a combination of two atoms of one sort with one of the other, will generally be effected more easily than one with one of each sort.

Cor. 4. Particles compounded of three or more atoms will possess polarity.

Prop. 17. If several equal tenacious atoms or particles, be placed in a straight line R, S, (*fig.* 32.) each atom having its atmospherule, and the atoms being placed at equal small distances, *viz.* so near together that their atmospherules act on each other by repulsion; then the extreme atmospherules, *viz.* those of A and I will be more extended towards R and S, than if there had been only two or three; those of the middle atoms, *viz.* at or near E, will be protruded in the direction E P, and E Q perpendicular to R S; and those which are nearer the middle will be more extended sideways, than those which are situated nearer to the extremities.

For the resistance opposed to the extension of the atmospherule of B towards C, produced by the actions of D, E, F, &c. will cause a greater pressure on A, than would have been in the absence of these atoms; therefore the atmospherule will be more extended towards R, where there is no external resistance. And evidently the atmospherule of E, being equally pressed on both sides, will be extended towards P and Q, the same holds of the intermediate atoms, but the pressure is not exactly equal on

both sides, and diminishes as we approach the extremities of the line.

Cor. 1. If the line R S contain a great number of atoms, extending to a great length; the central atoms to a considerable distance from the middle on both sides, will be nearly alike protruded in directions perpendicular to R, S.

Cor. 2. The nearer together, in the line R S, the centers of the tenacious atoms, or particles, are placed, other things being the same, the more will the atmospherules be extended.

Cor. 3. If several such atoms be placed near to each other, so as to form a slender rod or cylinder, similar effects will take place.

Cor. 4. If a pressure, or opposing force be applied to one extremity of the line, as at S, to counteract the extension towards that part; then will all the atoms in the line be affected, and the atmospherule of each will evidently be more protruded towards R.

Cor. 5. If instead of pressure a collection of ethereal atoms, were added to the atmospherule of I, similar effects would ensue.

Cor. 6. If a number of ethereal atoms were removed from I, the contrary effects would follow, and the atmospherules of A, B, C, &c. would extend more towards the side facing S.

Cor. 7. These effects will be influenced more or less by the forces, and the extent of the spherules of the tenacious atoms, or particles.

Cor. 8. If there be several such lines of atoms in one plane, constituting a plane figure as ABCD (*fig.* 33.) then it is evident, that the atmospherules on the boundary lines will be more extended outward in the plane, than when there is only one line; and those of the angular

atoms will be more extended in the directions of the diagonals, and those in the other parts of the plane in a direction perpendicular to the plane.

Cor. 9. If several such planes constitute a solid AF, (*fig.* 34, where the dots are designed to represent the centers of the tenacious atoms,) it is evident, that the atmospherules will be most of all extended at the angular points, in lines drawn through the solid angles, and more extended on the line or edges in the direction of a diagonal plane, than on the middle parts of the plane surface; and more on the plane surface outward, than in the case of a single plane.

Cor. 10. If a pressure be applied to one of the surfaces ABCD, perpendicular to that surface, its atmospherules will evidently be forced inward, and will produce pressure on the next adjoining plane, and this on the next, &c. so that the atmospherules of the extreme plane EFG will be more extended outward, as will also those on the linear edges, and angular points.

Cor. 11. If instead of a pressure, an additional quantity of ethereal atoms were communicated to the surface ABCD, similar effects would take place.

Cor. 12. On the contrary, if part of the ethereal atoms be taken away from the surface ABCD, the pressure against the atmospherules of the adjoining plane would be diminished, and the spherules of the several parallel planes would be more extended towards the plane ABCD.

Cor. 13. Those effects will vary according to circumstances, in some cases the ethereal atoms, added to one part of a line, plane, or solid, will be propagated with more or less facility to the adjacent ones, as the forces of the tenacious atoms are greater, and their spherules less.

PROP. 18. If a solid be constituted as in *prop.* 17. *cor.* 9. with plane faces, and having the several atoms with

their atmospherules uniformly arranged, and if the atmospherules be agitated, at small intervals successively, by a gentle force, vibrations will be excited perpendicularly to the plane surfaces, except that very near the edges they will deviate from the perpendicular.

It is evident that the vibrations will be produced, and the oblique directions of them are equally resisted on all sides of the central parts of the plane, hence the vibrations, except at the edges, must be perpendicular to the plane.

Cor. 1. The vibrations on the angular edges will be perpendicular to those edges, and in a plane between those which form the angle of the surfaces of the body.

Cor. 2. In solids terminated by spherical, or other curve surfaces, the vibrations will be perpendicular to planes touching the surfaces.

Cor. 3. The direction of the vibrations may be modified by the arrangement of the atoms constituting the solid.

PROP. 19. If a collection of tenacious atoms, each being totally enveloped in its own atmospherule, be contained in a vessel or given space, as in *figs*. 35, or 38, and subjected to some determinate pressure, variable within certain limits; and if the ethereal atoms be so far confined within that space, that they cannot, by the greatest limit of the given pressure, be made to escape, so much as to allow the contact of the spherules of the tenacious atoms, or particles; the collection will form a body having the properties of an elastic fluid, or gaseous substance.

For, it is manifest, the atoms will move freely among themselves on the application of a small partial force, and that a contraction or expansion will be produced by an increase or decrease of the pressure, since by the given pressure the centers of the ethereal atoms, resting on the spherules of the tenacious ones, and on each other, are

kept nearer together than they would be under a less pressure. The dots about the particles in *fig.* 35, are to denote the centers of the ethereal atoms.

PROP. 20. The atoms being disposed as in the last proposition, if under the given pressure the ethereal atoms can escape from the vessel, so much as to allow the tenacious atoms or particles, to approach very near to each other, but yet leaving such a portion of the atmospherules, that the ethereal atoms can move or pass on every side of the tenacious ones: the collection will form a body having the properties of a liquid.

For the freedom of motion of the atoms among themselves is still continued, but the space they occupy is greatly contracted, and the bearing now is chiefly between the spherules of the tenacious atoms, or the most powerful of them, and the centers of the ethereal ones contiguous to them; the atoms in *fig.* 35, being placed by compression or reduction of temperature, as in *fig.* 36, so that in *fig.* 35, it will have the form of a gas, and in *fig.* 36, that of a fluid, hence a considerable difference in the pressure in the last case, will produce only a small alteration in the volume; and thus the properties of a liquid will be exhibited.

Cor. If the atmospherules consist of two classes of ethereal atoms, one greatly exceeding the other, in their comparative forces, as in *prop.* 11. *cor.* 4; when the tenacious atoms approach to some certain distance, their mutual actions will tend to dissipate at once an abundant quantity of the less powerful ethereal atoms, and the liquid will be immediately formed.

PROP. 21. If under the given pressure, as in the foregoing propositions, the ethereal atoms escape, so much as to allow a close approximation of the others, on some of their sides, preventing the ethereal atoms, under that

pressure, from passing between them on those sides; the collection will form a body having the properties of a material solid.

For in this case the parts of the body do not admit of free motion among themselves, being strongly attached at the points of union, and therefore they cannot be separated without great force, as will appear from *prop.* 9.

In *fig.* 37 a new arrangement of the particles of *fig.* 36 is exhibited, see *phenomenon* 27. *sect.* iv. where the conversion of water into ice is explained, by the help of those figures.

Cor. 1. A solid thus formed will be more or less firm; harder or softer, more or less elastic, of greater or less volume; according to the forces, spherules, manner of junction and arrangement of the tenacious atoms.

Cor. 2. The ethereal atoms may still find great freedom of motion through the solid in an indefinitely great variety of directions.

Prop. 22. If several atoms be enveloped in atmospherules, the ethereal atoms being of one kind, or consisting of strata of different kinds; and if these constitute a gaseous fluid under a given pressure, and intensity; then if the force of the tenacious atoms be increased or diminished within certain limits, the volume will not be altered, provided that the pressure, and the intensity of the sides of the vessel, or power of transmitting ethereal matter, remain the same.

Let *fig.* 38, be a section of the gas: conceive for a moment, the capacity of the vessel to be fixed, and its sides made incapable of transmitting ethereal matter: and now let the force of the tenacious atoms be diminished by any quantity within such limits, that the centers of the ethereal atoms shall still be supported on the surface of the tenacious ones, while under the given pressure.

Now evidently, the ethereal matter is less compressed, as far as it depends on the mutual actions of the others, because of their diminished force, and the force of gravity on them is also less; consequently they will tend to expand, and press with increased force on the sides of the vessel; hence, the supposed restraining power being removed, ethereal matter will escape, till the equilibrium of the intensity is restored; and thus it becomes evident, that the given pressure will be sustained without alteration of volume; therefore a variation of force to a considerable degree, may take place without variation of volume, under a given intensity and pressure.

Cor. 1. It is manifest that if the force be diminished beyond the limits specified in the demonstration, a contraction of volume will ensue, and the gas will become a liquid or solid. For the tenacious atoms, not supporting the ethereal ones on their surfaces under the given pressure will break through the atmospherules, and resting on each other will become a liquid or solid.

Cor. 2. If the magnitude of the spherules be given, the whole quantity of ethereal matter requisite to support a given pressure, when the intensity is also given, will be greater or less as the force of the tenacious atoms is greater or less. For on a diminution of force, ethereal matter will escape, and on an increase of force, it will enter the containing vessel, and be more condensed on the surfaces of the spherules. This also follows, because the greater force of the atoms will produce a greater condensation of the ethereal matter.

PROP. 23. If the forces of the atoms, constituting a simple gas, remain the same, the radii of the spherules may be varied, in some degree, without alteration in the volume; the pressure and the intensity being given.

The same being supposed as in the last proposition, let

the radii be enlarged, and this will tend to expand and protrude the atmospherules, hence, if liberty be allowed, ethereal matter will escape through the sides of the vessel, till the given intensity is attained, and hence an equilibrium is produced, and the given pressure will be supported at that intensity. The converse is manifest.

Cor. 1. If the radii be diminished beyond certain limits the gas will become a liquid or solid, since the tenacious atoms will thus be capable of passing through the atmospherules.

Cor. 2. If the force of the tenacious atoms be given, the whole quantity of ethereal matter, requisite to support a given pressure, at a given intensity, is less when the radii are greater, and the converse.

Cor. 3. Hence, in general, the quantity of ethereal matter requisite to support a given pressure at a given intensity, will be as some function of the forces directly, and radii of the spherules inversely.

Cor. 4. Under the assigned limits of pressure, equal volumes of simple gases of different kinds, under the same pressure and at the same temperature, will contain an equal number of atoms.

Cor. 5. If a collection of atoms, at a given intensity and pressure, constitute a gas; the same collection at that pressure and intensity, might constitute a liquid, or solid, merely by increasing the force of the atoms or diminishing the radii sufficiently, or by both of these alterations.

Cor. 6. If there be two simple bodies, the one a gas, and the other, either a liquid or solid, at a given intensity and pressure; then, the atoms of the latter have either a greater force or a less spherule, or they differ in respect of both these.

PROP. 24. If a collection of atoms, constituting a gas,

be contained in a vessel at a given intensity; then the density will vary as the compressing force, provided that the pressure is within such limits, that the whole shall continue in a gaseous form; and that time is allowed for acquiring the given intensity, after the action of the compressing force.

Let the force be applied in very small portions at successive intervals, and such in quantity, that at each application, the density shall be equally increased, now after the first small increase of pressure the gas will act with increased force on the sides of the vessel, and consequently ethereal matter will escape till the intensity of the gas is reduced to the given intensity of the sides of the vessel; hence the resistance to the second application of the compressing force will be equal to that of the first, and therefore these two first small portions of compressing force will be equal; in the same manner it may be shewn that the third is equal to the second, and consequently to the first, and so of the rest; that is equal increments of density are produced by equal increments of compressing force.

Cor. 1. It is evident that if the pressure be such, that a portion of the gas is converted into a liquid, or solid, the above cannot hold, a portion of the gas being removed.

Cor. 2. The law of repulsion of the atoms does not determine the law of condensation, because the actions are modified by the escape of ethereal matter.

PROP. 25. When a gaseous body is constituted of atoms, whose forces at the surfaces of the spherules are equal, or nearly equal; they will be less disposed to combine, and form a new body, than when the forces differ considerably at those situations.

For the forces at the surfaces being equal, the ethereal atoms, forming the atmospherules, will have the same density at those surfaces, and will therefore be affected much alike by varations in pressure and the addition or abstraction of ethereal matter, and hence the atmospherules will not readily pass the one to the other, but will maintain themselves in a separate state on their own atoms, more firmly than when the forces are much greater on one surface than on the other, the circumstances being alike in other respects.

Cor. 1. When the spherules are also equal, the tendency to combine, for similar reasons, will be less than when they are unequal.

Cor. 2. Bodies constituted of particles, of which the forces of their atoms at the surfaces of their spherules are nearly equal, will in general be less stable and permanent than others whose spherules are of unequal magnitude.

PROP. 26. The actions of bodies upon atoms or particles affect their atmospherules, causing them to move towards, or from the body, according to circumstances; and thus rendering them more or less susceptible of union with other substances.

Let AB (*fig.* 43.) represent the upper surface of a body acting on the particle D*m*, at the side *m*, then it is manifest, that, if ethereal matter will readily apply itself to, and be diffused on AB, the atmospherule of D*m* will be brought chiefly towards AB, especially if the force of D be small; hence the atom *n* will more easily combine with D. On the contrary if AB have much ethereal matter already attached to it, so as to form on its particles extended atmospherules, it will resist the ethereal matter of D*m* at *m*, and hence will cause the atmospherule of D*m*

to extend more towards *n*, and hence will oppose the combination of *n* with D, by pressing on the parts at which they are nearest to each other.

PROP. 27. If a globular solid body A, (*fig*. 48.) be immersed or contained in a gaseous fluid, and both the body and the gas imbued with ethereal matter, so as to be in a state of equilibrium, the ethereal matter of the gas extending around its atoms equally on every side; and if now a considerable quantity of ethereal matter be communicated, by some means, to the solid body, and diffused over its parts, the atmospherules of the atoms of the contiguous gas will be extended outward from the surface of the globe.

For the ethereal matter communicated to the solid A, will be most of all abundantly diffused at its surface, towards which it will tend (*prop*. 17. and its *cor*.) hence evidently it will press on the atmospherules of the adjacent atoms of the gaseous substance on the side which is towards the solid A, and will therefore make them extend outward, as at *n* and *m*, &c. and the action of these protruded atmospherules will produce a similar effect on the next more distant ones, as at *p*, and *q*, &c. and hence the several atmospherules will be extended outward with diminishing effect, to a considerable distance from the solid A on all its sides, as shewn by the short lines on the little circles, which are intended to denote the spherules of the atoms of gas, the short lines shewing the direction in which the atmospherules are extended.

PROP. 28. The same things being supposed, as in the last proposition, except that the ethereal matter is, by some means now taken away from the solid, instead of being added to it; the atmospherules of the atoms of the contiguous gas, in this case will be extended towards the solid body A, as in *fig*. 49, on all its sides.

This is equally evident as the former, for the pressure of the ethereal matter, being removed in part, and chiefly (*prop.* 17. and *cor.*) from the surface of the solid A, that of the adjacent atoms of the gas as at *m* and *n*, &c. will extend towards A, and this diminishing the ethereal fluid on the further side of those atoms will produce a similar effect on the next stratum of the gas, as at *p*, and *q*, &c. decreasing gradually as the distance from A increases. The short lines drawn toward the solid in the figure, are to shew the sides on which the atmospherules of the gas are extended.

SECTION III.

Of the general Properties or Attributes of Matter.

When we examine the attributes and properties of matter, we find some which are totally inseparable, others are of such a nature, that sometimes they are found in bodies, and sometimes they are absent. Of the former kind are extension, figure, solidity, inactivity, mobility, attraction and repulsion. Of the latter sort are hardness, softness, fluidity, elasticity, &c.

It has been a question of debate, much agitated among philosophers, to ascertain what it is which constitutes the nature of bodies, or rather of the matter of which they are formed. Some make it to consist in extension, because this attribute first presents itself to the mind: but the same rule might lead us to draw other conclusions, since different views of the subject would suggest some other attribute first to our notice. Besides, all the properties of matter ought to be derived from its nature: now can this apply to extension? How can we derive from it, solidity, mobility, attraction, &c.? There may be conceived simple extension without any of these. Similar difficulties

press upon those, who place the essence of matter in *solid extension:* for how can we hence derive mobility, resistance to impressed action, attraction, or repulsion? These surely cannot flow, necessarily, from *solid extension.*

Will the same objections reach our theory, which places the essence of matter in attraction and repulsion, such that every atom may consist of a small central sphere of repulsion, pressed at every point by an extensive concentric sphere of attraction, resting on it with forces directed to the center? Do not the other properties of bodies flow from this? Cannot we derive from it, extension, figure, solidity, *inertia, vis inertiæ,* mobility and gravity, and even divisibility as far as it is known to extend in fact? The answers to these queries will be attempted in this section. The explanations of the less general properties will then follow. The phenomena which follow are acknowledged facts, the explanations are grounded on the theory, the truth of which is supposed to be granted.

PHENOMENON 1. Bodies of every kind and form, whether gases, liquids or solids, are made up of parts, which in many cases may be easily separated; and divisibility is a general property of bodies.

Explanation. Admitting that bodies are composed of atoms as described in *pos.* 1 and 2, *sect.* i. and in *prop.* 19, 20, and 21, *sect.* ii. it is manifest, that divisibility will belong to all bodies, since they are formed of distinct atoms adhering with finite forces.

PH. 2. Bodies are extended and susceptible of various figures.

Exp. Bodies constituted of atoms according to the theory must possess this property; for evidently the atoms cannot coincide, because of the infinity of their forces, at the centers.

PH. 3. Bodies admit of motion and rest.

Exp. This property necessarily appertains to the atoms described in the postulates, and consequently belongs to the bodies composed of them.

Ph. 4. Matter is impenetrable by the definite force of other matter.

Exp. This must result on the supposition that the matter which composes bodies, is such as pointed out in the theory, because, the force of the atoms at their centers is indefinitely great, and hence the centers, by a finite force cannot be made to coincide.

Ph. 5. Bodies and the parts of bodies, variously, by some means, act on each other, or are acted on, so that the result of the actions is the same as if they acted on each other, frequently approaching each other, or receding according to various circumstances, and modifications, as is abundantly evident from what we observe in gravitation and cohesion, in the reflections, inflections, and refractions of light, and caloric, the compositions, and decompositions of bodies, crystallization, and other phenomena of chemistry, and indeed in all the changes which take place in bodies.

Exp. All this will follow as an immediate consequence, on admiting that matter is constituted as in the postulates. That the law of force, assigned to the atoms, is adequate to explain the several cases of attraction and repulsion, will be seen in the particular exposition of the phenomena.

Ph. 6. Bodies are inert, that is, they cannot change their own state.

Exp. This will be true of bodies constituted as in the theory, by *prop*. 2. *sect*. ii.

Ph. 7. Bodies possess a *vis inertiæ*, or an innate force opposing any change in their state.

Obs. Some have objected to the notion of a *vis inertiæ* as a real force, but it is a property of bodies, because a

given change in a body cannot be effected but by a determinate force; and although the least force will move the greatest body, yet the velocity produced will be proportionately small: again, did not this force exist, the effect arising from the impact of one body striking another would be governed by no law, but we know that to move a given body with a given velocity requires a given force.

Exp. This will hold of bodies formed according to the theory, as appears from *prop*. 3. and *cor*. 1. *sect*. ii.

Note. This constitutes the first law of motion.

Ph. 8. The *vis inertiæ* of bodies is proportional to the quantity of matter they contain.

Exp. This follows from *prop*. 3. *cor*. 3. *sect*. ii.

Ph. 9. The motion or change of motion of bodies, is in proportion to the force impressed, and is made in the direction in which the force acts.

This is usually called the second law of motion, and is found to be universal as far as experiments and observations extend.

In order to make this more intelligible, we may suppose, that a given force, operating at once on a given quantity of matter or body, will produce such a change in its state, that, at the end of a given time, it will be at a certain determinate distance, taken in a straight line in the direction of the force, from the place, which it would have been in, had not the force been applied; and this proposition asserts that a double or treble, &c. force, in the same direction, would cause the body to attain a double, treble, &c. distance, or, that the same force acting on a double quantity of matter, would have caused it to pass through half the distance, which is an equal change, since as much as two equal bodies have each received half that change.

Instead of double, or treble, &c. any proportion of force,

and also any quantity of matter acted on, may be supposed.

Exp. Let a given force be applied, so as to act on the center of a given atom on one side, this will destroy the equilibrium of the constituent forces, and the force on that side will prevail by the quantity which is put in action, and consequently will produce some motion in that direction, and hence the atom is put into a new state, which, since the force has ceased to act, it will retain by *ph.* 7, or the first law of motion. Now let the same force be again applied in the same manner on the atom, an effect equal to the former will be again produced, or, which is the same, let a double force be applied at once, and the velocity of the motion in that direction will be doubled, and, in like manner, for any quantity of force there will be produced a proportionate velocity.

Again let the same force be applied in the same way to the center of an atom of a double power (that is, containing a double quantity of matter;) then the equilibrium is destroyed as before, but the velocity of motion is opposed by a double force, and will therefore according to the preceding part be only half as much: the same reasoning will hold good whatever may be the ratio of the force constituting the atom, and therefore the velocity produced by a given force will be inversely as the force of the atom moved. And if several atoms be so connected as to form a determinate body, it is manifest that the same reasoning will hold true of this body, therefore, &c.

PH. 10. Action and reaction are equal and in contrary directions; this is equally evident with the preceding, from innumerable experiments, and constitutes the third law of motion.

Exp. Let any force act on the center of an atom, the

equilibrium of the forces on its center is at that instant destroyed, and the difference of force at the opposite sides is at that instant equal to the acting force; this acting force, then balancing or neutralizing an equal opposite force, is itself neutralized, and its only effect is to change the state of the atom at the instant of its action, so that the action and re-action equally counteract each other in the change of state which is produced.

Ph. 11. All distant bodies are under the influence of some force, by which they have a tendency towards each other, and this force is found to be proportional to the quantity of matter directly, and to the square of the distance inversely; it is denominated attraction, and has more particularly been called the attraction of gravitation; and the law of its action, above stated, is called the law of gravitation.

Exp. According to the foregoing postulates, any two atoms of matter will evidently affect each other in this manner, and according to this law, and hence it follows, that distant bodies composed of any number of atoms will be under the influence of the same law; for, (by *Mech.*) the force of the whole body will be equal to that of a single atom, equal in force to the sum of the atoms composing the body, and placed in their center of gravity, or center of parallel forces.

Scholium. From the explanations already given of the phenomena of bodies, respecting their general properties and actions, it is manifest, that the whole doctrine of statics, and dynamics, and all the phenomena of gravitation, or the actions of bodies at a distance, may be explained as in the best treatises on Mechanics and physical Astronomy.

On this account the pages of this work will not be oc-

cupied in explanations of these subjects, but the reader is referred to the excellent Treatises on Mechanics by Dr. *O. Gregory*, *Wood*, *Whewell*, and *Venturoli*; *Newton's Principia*, and the Treatises on Astronomy by *Gregory*, *Kiel*, *Vince*, *Woodhouse*, *La Lande*, *&c.*—and the *Mechanique Celeste* of *La Place*.

SECTION IV.

Phenomena relating to several Properties of Bodies and their Change of Form.

Besides the general properties of bodies, there are other particular ones innumerable, depending on the kind, connection, and other relations of their parts, their motions, &c. Hence arises a great diversity and variety in the masses of matter, which constitute our globe. The differences are manifest in their colours, degrees of hardness, and firmness, their weights or specific gravities, their elasticity or spring, their texture, porosity, and many other qualities; but one grand distinction becomes very manifest, whenever we direct our minds to the investigation of philosophical enquires, and that is the very great difference continually observable between what we sometimes call common matter, and those subtile agents denominated light, heat or caloric, and the electric fluid.

Such is the difference, that the latter by some have been considered rather as certain properties of bodies than as real substances; others rejecting this notion, have recognized them under the terms imponderable, radiant, or ethereal matter; and this view is almost universally admitted to be the most probable. That light is a real ma-

terial substance, emanating from luminous bodies, appears from several considerations.

1. Whenever light is present, so as to render objects visible, either the sun or some other heavenly body, or the mutual actions of some substances producing the light, must be in a situation where they are exposed to the place.

2. The motion of light is progressive, being known to occupy about eight minutes in moving from the sun to the earth : this has been clearly proved by *Roemer's* observations on the eclipses of Jupiter's moons, and confirmed by the researches of Dr. *Bradley* on the aberration of the stars.

3. Its progress may be stopped by the interposition of an opaque body, and the shadow, or obscuration produced, proves that the light, in an uniform medium, moves in straight lines.

4. It enters into and passes through certain substances, which are said to be transparent, and, when it falls obliquely on them, it is bent or refracted at the surface.

5. A large portion of light is reflected at the surfaces of the bodies on which it falls, especially when the surfaces are smooth and polished : the rays being in this case copiously returned with great regularity, the incident and reflected ray making equal angles with the perpendicular to the surface.

6. By means of refraction or reflection at curved surfaces, a multitude of rays can be collected into a small space or focus, producing there a strong light, and exciting an intense heat on the opaque bodies, exposed to the focus of the rays.

7. Some bodies, on which the light falls, seem to obsorb a considerable part of it, so that it disappears.

8. All bodies, less or more, disperse in all directions some part of the light falling on them.

9. When the light falls on a crystallized body, whose primitive form is not a cube, or octahedron, its rays are divided at the surface, and pass through the crystal in two different directions; and the unusually refracted ray acquires peculiar properties.

10. When a ray of light falls on the polished surfaces of transparent bodies, at a certain angle, different for different bodies, the reflected ray acquires properties analogous to the ray unusually refracted by a crystal.

11. When a small beam of light passes through a triangular prism, it is divided into parts by unequal refraction, exhibiting on a screen a figure, or spectrum, containing seven distinct classes of colours; that which is least refracted, occupying the extremity nearest to the direction of the original beam, is red; and the other extremity, or the light most refracted, is violet; the order of the colours being red, orange, yellow, green, blue, indigo and violet.

12. Each of these colours is permanent, for any one of them being any how reflected or refracted always shews the same colour.

13. Two or more of these colours being mixed, by being refracted to the same place on a screen, give a colour different from the primitive ones.

14. All the colours of the spectrum, being so refracted as to fall on the same place on a screen, give there the appearance of a white speck like that of the original beam.

15. The different sorts of rays as separated from the beam of light by the prism, have different degrees of illuminating power; that is, a small object will be more illuminated by the light of one colour than by that of another.

16. Light is necessary for the healthy vegetation and

maturity of plants; those which grow in the dark become destitute of colour and smell, they contain an excess of saccharine and aqueous particles, and are rendered less combustible; the culture of celery affords a remarkable instance: and even animal life itself requires the presence of light.

17. There are certain bodies called solar phosphori, which by being exposed a short time to the light, acquire the property of shining in the dark. Thus, if a mixture of the powder of calcined oystershells and sulphur be put down closely and compactly in a crucible, and kept red hot for about an hour, the substance, being cooled, may be preserved in a phial, and will possess the property above noticed: it must be remarked, that to whatever sort of light the solar phosphorus has been exposed, the light which it emits, is always that of a pale yellow, and not that of the particular colour in which it had been placed.

18. Light produces great chemical changes on bodies; thus if chlorine and hydrogen be mixed, they combine slowly in the dark, but more rapidly in daylight, and in the direct rays of the sun they frequently unite by sudden explosion. Nitrate of silver is soon reduced in the blue and violet rays, producing a blackness on the paper, which has been dipped in a solution of the nitrate, and placed in those rays.

19. Light has never been found collected in separate masses, but variously manifests its existence in several bodies.

20. Light has the property of exciting in us the sensation of vision, by moving from an illuminated object to the eye. All of these, and many other properties of light, may be best explained on the supposition, that it consists of material atoms emanating from luminous bodies.

It is not necessary to suppose that the atoms of light

differ from those of other bodies, except in the quantum of their constituent forces, which must be very small,—on this account they will not cohere, they are thus easily projected by the vibrations excited in bodies, and are suited to move with amazing rapidity, and to excite vision through the medium of the humours of the eye, the retina, and optic nerve. Small differences in the forces and extent of the spherules of the atoms of light will be sufficient to account for the different sorts, their different refrangibility, and their property of producing different colours, with other similar effects. To explain the 9th and 10th properties above mentioned, polarity has been attributed to them, or at least they have been thought to be capable of polarization; but this is not necessary, since the vibrations, excited in the bodies, on which they fall, are propagated to the adjacent medium, differing according to the nature and position of the body; and those circumstances are sufficient to explain the curious fact, to which allusion is there made.

The 17th property has been brought as an objection to the materiality of light; the solar phosphori appearing of the same colour to whatsoever sort of light they have been exposed. But this objection has no weight, since it is not at all necessary to suppose, that they emit the identical light, which falls on them; they contain in themselves abundance of this subtile fluid, and exposure to the action of light excites in them suitable vibrations, propagating not only the small quantity of light which they had imbibed, but a portion of that also which they contain, causing them by this means to shine; and hence, since they shine principally by the light which themselves contain, they ought always to be of the same colour. To enter into the particulars of these properties, and the phenomena connected with them, would require us to intro-

duce the subject of optics; but this I have purposely postponed, with the design of taking up the subject hereafter, unless it should be done by some more able hand. From what is here advanced, we are authorized to admit light as a species of ethereal matter, see *def.* 32. *sect.* i. where the distinction between tenacious and ethereal atoms is noticed.

Heat, or caloric, appears to be also a species of ethereal matter: it has several properties in common with light, and some others, which will be noticed in the explanations of several of the phenomena in the sections of this work; from which we are led to conclude, that its atoms are more powerful than those of light, and hence that they move with less rapidity in radiation. The electric fluid is equally entitled to the rank of a material substance. In some particulars it agrees with caloric, and in some even with light; it is probably constituted of atoms more powerful, and having smaller spherules than either of the former, and hence cleaves more closely to the atoms of common matter, which we have named tenacious atoms, and especially to the surfaces of bodies: see *sect.* vii. It is observable that if certain gases, especially oxygen gas, be compressed, heat is excited, and if the pressure be sudden and forcible, light and even electricity are produced.

The electric fluid may by certain means, shewn in *sect.* vii, be greatly concentrated, and in this state made to pass through a card, or even a quire of paper, leaving a hole of considerable diameter, through which it has passed, and which has a sulphureous scent.

These are strong indications of its materiality. If the reader still has doubts respecting these conclusions, he will probably have them entirely removed by consulting the 7th section. It will be scarcely necessary to observe, that the differences which occur in the affections of light,

caloric, and electricity, can be no objection to their being material substances, since the same objection, if admitted, would exclude the materiality of all substances.

Bodies imbued abundantly with ethereal matter will not experience any sensible differences, on that account, in their weight, because of the indefinitely less force, which constitute such atoms. It follows, from a view of the very small force of the ethereal matter, that a vast quantity of it will be crowded into a small compass, around the several atoms of tenacious matter, and will be attracted by them, so that their centers shall fall deeply into the spheres of each other's repulsion, (*props.* 11, and 12, with their *cors.*) and this closeness will he increased by external pressure; hence they are always in a state ready to fly off with great velocity, whenever a disturbance takes place in the bodies, in which they are thus condensed. All this answers to what we know of radiant matter. And whosoever carefully examines the numerous properties, and effects of light, heat, and the electric fluid, in which they resemble the properties and effects of common bodies, and contemplates their reciprocal actions, will find it difficult to conceive, that they are any thing but real matter, especially since not a single phenomenon can be better explained by substituting any other suppositions for that purpose.

Ethereal matter, it is well known, performs various important offices in the economy of nature; among others, the change of form produced in bodies, that is, their conversion from the solid to the liquid, and from the liquid to the gaseous form, and the converse, has excited considerable attention. In these changes caloric is particularly concerned, being frequently given out, or absorbed, in abundance, at the moment of the conversion from one form to another, and a certain quantity of this subtile fluid is necessary, under a given pressure, to maintain the differ-

ent bodies with which we are conversant, in any condition as a solid, liquid, or gas: for instance, if the temperature be more than 40° below zero of Fahrenheit, mercury is a solid; from that to an elevation of about 660° it is liquid, and when its temperature is raised above that point it becomes a vapour or gaseous fluid. Water is a more familiar instance—the temperature being below 32° of Fahrenheit, it is solid ice; when above that to 212° it is liquid water, and the temperature exceeding 212° it is vapour or steam: the substance is here supposed to be under the usual pressure of the atmosphere.

The most striking phenomena respecting these changes, as they affect water, will be laid before the reader in this section.

Ph. 1. Bodies are susceptible of the solid, liquid, and gaseous forms.

Exp. That these forms may arise from the manner of the union of atoms will appear from *props.* 19, 20, and 21.

Ph. 2. Besides solids, liquids and elastic fluids, various appearances indicate the presence of indefinite quantities of ethereal matter, which is generally presented under the denominations of light, caloric, electric fluid, &c.

Exp. All these and innumerable varieties of each of them, may be formed of atoms as expressed in the postulates, and farther explained in *def.* 32. This and the preceding explanation will be abundantly illustrated, and confirmed, as we proceed to explain the phenomena to which they are particularly related.

Ph. 3. There are various sorts of solids, differing greatly in texture, weight, firmness, and various other properties.

Exp. All this may easily be conceived to arise from small differences in the forces of the atoms, and the radii of their spherules.

Ph. 4. Solid bodies in general are found to contain much ethereal matter.

Exp. Although the atoms of ethereal matter cannot easily adhere to each other, because of their small forces, yet they will adhere strongly to tenacious atoms whose forces are evidently sufficient to cause a multitude of ethereal atoms to approach them, and to adhere so closely as even to bring the centers of these ethereal atoms to a considerable distance within each other's spherules.

Ph. 5. Caloric, electricity, &c. pass along solid bodies with very different degrees of facility.

Exp. This will depend on the forces, and arrangements of the particles composing the solid; when the texture and disposition of the parts are such, that the ethereal matter can form atmospherules, quite distinct, about the several particles of the body, it will be a slow conductor of ethereal matter, and the same will follow if the atmospherules are nearly disjoined.

Ph. 6. Many changes are continually going on, in the decomposition, and the new production of bodies.

Exp. The mutual actions of atoms, various in their constituent forces, and in the magnitudes of their spherules, must needs, under various and changing circumstances, produce these changes.

Ph. 7. Bodies of the same kind, are the same in all their properties, throughout all ages of the world.

Exp. This must follow in consequence of the unchanging nature of atoms of the same kind, (*pos.* 1, and 2.)

Ph. 8. All bodies tend towards the earth in lines, perpendicular to the horizon. The force required to prevent their falling is called their weight.

Exp. This is a necessary consequence of the united actions of the atoms composing the earth, on those which compose the body. And evidently the weight will be as

the sum of the forces of all the atoms contained in the body, for the action of the earth is given.

PH. 9. Many vacuities are found in bodies, and these are of very different magnitudes and forms in different bodies.

Exp. Atoms of different kinds must admit of various combinations to form particles, and these may be variously united to form bodies, hence, the smallness of the spherules being considered, there will be innumerable pores in magnitude and form, agreeing to the dispositions of the constituent particles.

PH. 10. The same body may exist under the different forms of a solid, a liquid, or a gas. Thus, water at a high temperature becomes steam, and at a lower it is converted into ice.

Exp. These changes are the natural results of the presence of different quantities of ethereal matter, by which the atoms or particles of the body are kept at different distances. The particular phenomena attending these changes will be noticed in several instances.

PH. 11. The same body is found to contain more caloric, when it is in a gaseous form, than when it is liquid, and more when liquid than when solid.

Exp. The greater quantity of ethereal matter is requisite to keep the particles farther asunder in its expanded form, and evidently this accords with the theory.

PH. 12. Light and caloric often pass from bodies with very great velocity.

Exp. The ethereal atoms form atmospherules, by the forces of the tenacious atoms, which forces also cause the centers of the ethereal ones to lie much within each other's sperules: now when in the composition of bodies, changes are produced, or vibrations are caused among the constituent atoms or particles, multitudes of ethe-

real atoms will be projected with great force; and because of their own minute power they will move (*ph.* 9. *sect.* iii.) with very great velocity.

PH. 13. The actions of caloric, light, &c. are different on different bodies.

Exp. This necessarily will follow, not only from the difference in the tenacious atoms, composing the bodies, but also from the different ways in which they are combined.

PH. 14. Light, caloric, and the electric fluid, in various cases, and under several circumstances, pass through solid bodies.

Exp. That ethereal matter in rapid motion, or under the influence of force, may thus pass through solids, if matter be constituted as in the theory, is evident from *prop.* 21. *cor.* 2. *sect.* ii. and *ph.* 9. *sect.* iii.

PH. 15. When a gas is compressed, caloric is evolved, the temperature is raised, and the elasticity of the gas is encreased.

Exp. Conceive the gaseous body to be contained in a vessel as AB (*fig.* 38. *plate* ii.) the vessel itself being contained in an extensive space of similar gas of the same temperature, and capable of slowly admitting through its sides, a passage for the ethereal, but not for the tenacious atoms; and conceive the gas, in AB, to be compressed, (suppose by means of the piston P), now it is evident, that every atom in the vessel exerts a greater force of repulsion through the medium of the intervening ethereal matter, because the distance between the several atoms is diminished by the pressure. Hence the resistance to pressure, and tendency to expand, that is, the elasticity is increased; and the equilibrium of the ethereal atoms, between the exterior gas, and that within the vessel, is destroyed, and hence the ethereal atoms tend

to enter the sides of the vessel, and will begin to escape through them, and further, the disturbance occasioned by this action in the gas will cause vibrations to ensue, producing a rapid projection of ethereal atoms, (*viz.* those of which caloric may be constituted *ph.* 2.), and thus we have the evolution of caloric, and increased temperature. For similar reasons the pressure may be so great and sudden, that light also and electricity shall be evolved.

PH. 16. When the pressure on a gas is diminished, caloric is absorbed, and the elasticity and temperature are diminished.

Exp. This is only the converse of the foregoing, and the cause of it will sufficiently appear from an inverse procedure in the reasoning.

PH. 17. When atmospheric air, and other permanent gases, are freed from moisture, and compressed, at intervals; the compressing force varies as the density of the gas, or inversely as the space it occupies, at least, this is true within certain limits of pressure. (*Biot's* Physique, vol. i. chap. vi. and *Thompson's* Chemistry, vol. iii.)

Exp. Conceive the gas in AB, (*fig.* 38, plate II.) to be compressed by a force applied to the piston P.

Now if no atoms could escape through the sides of the vessel, the density would vary as the 4th root of the cube of the pressure, (*Newton sch. prop.* 23. B. 2.) but during the compression much caloric escapes from the vessel, containing the gas, which is well known and agrees with *ph.* 15; also intervals between the times of the action of the compressing force are requisite, in order that the law of compression above stated may hold in fact.

But according to our theory ethereal atoms will escape through the sides of the vessel (as appears from *ph.* 14, and 15.) and that more and more as the pressure is increased, hence the density will be increased, both by the

pressure, and by the loss of ethereal atoms (their absence allowing the access of the others,) and also, since the escape of the caloric from the vessel depends on the pressure, it will evidently render the resistance uniform, time being allowed for its extrication; and hence the density will vary as the pressure.

Sch. It has been demonstrated by Sir *I. Newton,* that if the particles of an elastic fluid repel each other, with forces inversely as the distances of their centers, the compressing force will be as the density; hence from the above fact of the air's compression, some have concluded that the atoms of air thus repel each other: but it ought to be observed, that Sir *I. Newton* has, in that proposition, supposed, 1st that the remote particles of the gas do not act on each other, now here they will act by attraction, which will have some effect, especially as it respects those adjacent to the atoms in question, and this effect increases greatly with the diminution of distance; 2dly. He supposes that no atoms escape from the space confining the air, but they do escape as shewn in the preceding phenomena, and it is found necessary in making the experiments to allow a short time between the several successive pressures, for the evolution of caloric; otherwise in fact the densities are found to increase in a slower ratio than that of the compressing force.

Thus, *Biot* after describing the experiments, and proofs of the constant ratio of the compressing force and density, adds; " Pour ne rien omettre, je dois dire encore que, les experiences sur la compression et la dilatation de l'air ne seraient pas tout-a-fait exactes si on les faisait succeder les unes aux autres avec une grande rapidité; car en comprimant l'air, il se developpe de la chaleur; en le dilatant il se produit du froid, et cette chaleur ou ce froid augmente ou diminue son volume sous la mê me pression. Ces

causes accidentelles influeraient donc sur le volume de l'air d'une maniere rétangére aux phenoménes que l'on considere, si on ne leur laissiat pas le temps de se dissiper; et il suffit pour cela de quelques instans." (*Biot's* Traite de Physique, vol. i. p. 117.) And this corresponds with what is stated in the three last phenomena.

Now since the escape of the ethereal atoms will be greater, as the pressure is greater, it is evident that the fact here stated, will, from the circumstances of the case, accord with the law of force assigned in this theory to the atoms of matter. See note (B).

PH. 18. Vapours, and some gases formerly accounted permanent, may be reduced to liquids by pressure, and the abstraction of caloric; but there are some gases, which continue permanently such under the greatest pressure, and the lowest temperature, which we can apply.

Exp. According to the theory, tenacious atoms will retain about them atmospherules of ethereal matter, as in *prop.* 20, with greater or less energy, according to their absolute forces and the extent of their spherules; hence to reduce elastic fluids, composed of them, to a liquid form, will require a greater or less freedom for the ethereal atoms to escape from the containing vessel, combined with a greater or less pressure, and they may be reducible or not by such increased pressures, and diminished temperatures, as we can command.

PH. 19. Different gases of equal volume, and temperature, give out different quantities of caloric, when submitted to equal pressures, and the converse. (*Gay Lassac.*)

Exp. This is a consequence arising from the different forces and magnitudes of the spherules of the tenacious atoms, since on that account, they require different quantities of ethereal atoms to give them the same elastic force. (*Prop.* 22, and 23, *sect.* ii.)

Ph. 20. Gases expand by an addition, and contract by an abstraction of caloric.

Exp. It is evident that the atmospherules will be increased by the accession of ethereal atoms, and this evidently will increase the volume, the pressure being the same; and the converse is equally evident.

Ph. 21. Equal volumes of different dry gases, of equal temperature, and under equal pressures, are equally increased by the same rise of temperature.

Exp. Let the different gases, suppose oxygen and hydrogen, be contained in AB and CD, (*fig.* 38, and 39,) under equal pressures, P and Q; now since the ethereal atoms, which compose the atmospherules of the atoms in the surrounding air, and sides of the vessels, are, because of the given temperature, in a state of equilibrium with those within the vessels, supporting the given volume under the given pressure, there will be an equal tendency in both vessels to receive or to give out caloric, when there is an elevation or depression of temperature without; and since the resistance to expansion or contraction is the same, because of the equal pressures, their increase or decrease of volume will be the same for all equal differences of temperature.

Note. It has been found by experiment that the increase of volume is $\frac{1}{480}$ of the whole volume for each degree of Fahr. from 32° to 212°.

Ph. 22. Gases and vapours, not uniting chemically so as to form a new body, and having a sufficiently free communication, tend to mutual diffusion, equally, and uniformly through the vessel, and this occurs, although with less facility, even when the specific gravities are different, and the heavier is placed under the lighter; and when the gases are once equally diffused, they remain in that state. *Henry's* Chem. vol. i. 245. *Thompson's* Chem. vol. iii. p.32.

Exp. Let AB (*fig*. 40.) be the section of a vessel, of which the part AD is filled with a gas, whose tenacious atoms have a large spherule, and a small absolute force, (suppose hydrogen); and let the part CB be occupied by a gas, whose spherules are smaller but the absolute force much greater, (suppose oxygen).

Now if the part AD were removed, the remainder EB would diffuse itself through the vessel, or if EB were removed the rest would be in like manner diffused, because the centers of the ethereal atoms are in each other's spherules: and because the spherules of *c* and *d* are less than that of *b*, a more ready passage will be made between *c* and *d* for *b*, than if the spherules had been larger, and the inequality of the spherules will, therefore, admit of the expansion of the one gas between the parts of the other.—Also the attraction between *b* and *c*, and between *b* and *d*, is greater than between *b* and *a*, or *b* and *f*, which will also tend to bring *b* between *c* and *d*; and the more readily will this be effected if we consider three atoms, such as *c* and *d* forming a triangular base on the center of which *b* rests; now as soon as *b* is so far depressed as to come between *c* and *d*, it will immediately be brought under *c* and *d*, since the smaller spherules will approach each other; again the more powerful atoms, especially if their spherules are less, will be surrounded by more dense atmospherules, which, besides being itself a circumstance favourable to the mixture, will occasion a transmission of the ethereal atoms from those of one kind to those of the other, facilitating the effect; also when the change is effected in respect to one atom, the motion produced will contribute towards the mixture of the others.

Hence it is easily seen, that a small difference in the forces, and extent of the spherules of the tenacious atoms,

will have the effect of producing an equal diffusion of the gases, with greater or less facility, even when the heavier gas is below the other; but the diffusion will be more rapidly effected, when the heavier gas is placed uppermost, or when agitation is employed. See note (C).

Ph. 23. The uniform mixture of gases is effected more rapidly between gases of some sorts, than between those of other sorts.

Exp. According to the foregoing explanation, (*ph.* 22.) the facility of uniform admixture depends on the ratio of the radii, and forces of the different tenacious atoms, which compose the gases, and hence evidently there will arise a great variety of difference in the time of equal diffusion.

Ph. 24. In the simple mixture of gases, the volume remains unaltered; and consequently the mixture is of the mean specific gravity.

Exp. Since the volume is sustained under a given pressure by the equilibrium of the atmospherules of the inclosed gas, and those of the exterior air or gas, and the sides of the vessel (*ph.* 17.) and since the number of distinct atmospherules is the same, before and after mixture, it follows, that the total volume will remain unaltered, other things being the same.

Obs. The three preceding explanations apply to vapours, the temperature being given, and the pressure such as not to condense the vapour.

Vessels with large pores are found, in many cases, to afford a communication between the exterior and contained gases, sufficiently free to produce the mixture, a sufficient time being allowed for that purpose.

Ph. 25. Gases, during their conversion from the gaseous to the liquid state, give out caloric without any remarkable reduction of temperature.

Exp. This will be found to be a necessary consequence of the change by *prop.* 20, *cor.* whether the gas be simple or compound.

For example, let *fig.* 35, represent steam at a temperature above 212°, Fahr. and under the medium pressure of the atmosphere, each particle being supposed to consist of one atom of oxygen and two of hydrogen, which seems most probable, but various other figures and combinations may be conceived at pleasure; without much affecting the illustration; now imagine each particle to be enveloped in an atmospherule, as in *fig.* 29, consisting of different sorts of ethereal atoms, *viz.* caloric, light, and electric fluid; the last probably being of much greater absolute force, and having less extensive spherules, than the others.— Now as the temperature diminishes, the ethereal atoms, especially those of caloric and light, gradually escape, the volume of course contracts, and the particles approach, and the forces between them increase, hence when at a certain distance, and consequently deprived of a certain quantity of ethereal matter, *viz.* in the example here supposed, when the temperature has descended below 212°, the attraction between the tenacious atoms, and the reduced temperature, become sufficient to overcome the resistance of the extended atmospherules, and to bring the particles together, so as to take the form in *fig.* 27, or 28, instead of that in *fig.* 29, consequently the particles in *fig.* 35, will be reduced to some such position as in *fig.* 36; at the moment this occurs, the effect will be evidently, as the figures indicate, to dissipate and remove a very great part of the light and caloric, while the more powerful atoms of electric fluid, with the remaining caloric and light, adhering closely to the surfaces of the particles, are still sufficient to prevent firm adhesion, and to preserve the

character of fluidity now exhibited in the liquid form. See *prop.* 11. *cor.* 4. and *prop.* 20. *cor.*

Thus the proposed theory affords a clear explanation of this important change.

Sch. In order to set this interesting subject in as clear a light as possible, it may be observed, that we admit of great differences of material atoms, in respect of their forces, and the magnitude of their spherules (*pos.* 2. and *def.* 32.) and although there may be considerable difficulty in finding the relations of the forces, and magnitudes of different atoms (this being a difficulty hitherto thought to be insurmountable,) yet in many cases we may find some probable relations of these quantities, and if they should ever be ascertained in respect of two or more atoms, the investigation of others will be facilitated. Let us then notice, for illustration of the present subject, the combinations of hydrogen and oxygen. Several phenomena render it very probable, that a particle of water is composed of two atoms of hydrogen, and one of oxygen; on this ground, the force of oxygen will be 16, that of hydrogen being accounted 1, because, on our supposition, equal volumes will contain an equal number of atoms, which agrees with *prop.* 22 and 23. *sect.* ii. and therefore the relation of their specific gravities will be that of the forces of the atoms; also it is probable, that the spherule of hydrogen is greater than that of oxygen, both from what we shall here notice, and from its greater power of refracting light. Now in the *figs.* 25, 28, and 29, let B and C represent atoms of hydrogen, and A an atom of oxygen, *fig.* 29 will represent steam, *fig.* 28 a particle of water, and *fig.* 25 peroxide of hydrogen. Here we suppose the force of oxygen to be 16 times that of hydrogen, but the radius of its spherule only half that of hydrogen. It is known

that peroxide of hydrogen is a combination much more feeble, than that of water or steam, and this agrees to *fig.* 25, for here the cohesion between A and B is as 17, the force of the oxygen A, being 16, and that of the hydrogen B, 1, but this is opposed by their joint action on the ethereal matter at *m* and *n*, towards P, in the line of equilibrium PR, also the external pressure, and the increased atmospherule in this case, tend more to destroy the combination by their action at *m*, *n* and P, than to increase it on the other sides. Hence the combination is feeble, and cannot exist at high temperatures, (which agrees with fact) while also at a low temperature, it will be less liable to take the form of vapour than the combinations in *fig.* 28 and 29, which answer better to the condition of water and steam, and their conversion from the one form to that of the other. For in *fig.* 28, the combination is maintained by the force of A on B and C, and by the forces of these on each other; but these forces are opposed by the ethereal atoms which act on the convex sides of B and C between them, as at *n*, *o*, *p*, *m*, *r*, *q*, but not by those on the opposite sides; hence under a given pressure, when the temperature is increased, till B and C begin to separate, the retaining force will greatly diminish, but the separating force also diminishes, since the actions of the ethereal atoms rest more on A, as is seen in *fig.* 29, the given pressure also now concurring to prevent separation, which in *fig.* 25 it tended to produce; and moreover, when the position of *fig.* 29. is attained, the actions of both B and C are attractive, both towards each other, and towards A, and consequently a position of powerful stability is produced, which agrees perfectly with the nature of steam; also, at this change of form, a great quantity of caloric is absorbed at *m*, *n*, *o*, *p*, *q*, *r*, serving to form the gaseous at-

mospherules, as is evident from a little attention to the subject. (See *ph.* 42. *sect.* vi.)

These phenomena will be more or less as here explained, according as the spherules of B and C, and their forces are greater or less.

This view of the subject also answers to the formation of ice (see *ph.* 27.) and to the decomposition of peroxide of hydrogen, as will be seen when treating that subject, *sect.* vi. *ph.* 40, and following.

Ph. 26. A liquid on the contrary, in becoming gaseous, absorbs caloric without any remarkable change of temperature.

Exp. This is only the converse of the former.

Thus when heat is applied to water till it attains 212°, steam begins to form under the atmospheric pressure; for, as the temperature continually rises, the liquid expands till, at length, the atoms are so far removed from each other, that the particles of water, *fig.* 28, take the position in *fig.* 29, and the atoms of caloric are absorbed in abundance at *n*, *m*, *o*, *p*, *q*, *r*, forming atmospherules around the atoms exposed to its immediate influence; hence the gaseous state ensues, as explained above, and the gas rises through the liquid in the form of vapour; thus it is seen, that, at the moment the gas is formed, much caloric will be absorbed to form the extended atmospherules.

Obs. Probably the temperature at the point where the steam is formed is much higher than 212°, but on absorbing the caloric it becomes 212°, equal to that of the main body of the water, at least the phenomena favour this notion.

Ph. 27. Water, in assuming the solid form of ice, increases $\frac{1}{8}$ in volume, and gives out caloric, and electricity. (*Henry's* Chem. vol. i. p. 262.) Also the particles

becoming ice, take an arrangement such as to form prismatic crystals, crossing at angles of 60° and 120°. (*Thompson's* Chem. vol. i. p. 80.)

Exp. Taking *fig*. 36. for the liquid form of water, as in the explanation of *ph*. 25, and conceiving the temperature continually to decrease, then part of the caloric and light, contained in the liquid, will gradually rise, and escape at the surface, and the particles of the fluid will approach each other, causing a contraction of volume; now this will tend to obstruct the egress of the ethereal atoms rising from the interior of the liquid mass, so that, while the upper sides of the particles, (constituted as here supposed, or in various other ways, which the theory will admit of) being most exposed to the cold, begin to approach each other, on account of the evolution of caloric, and the lower sides begin to expand on account of the caloric rising towards the surface; the position therefore of the particles will be changed, from that of A, *fig*. 36, towards that of A, *fig*. 37. Hence, after a certain term, an expansion, instead of contraction, may ensue, and the temperature, being still farther reduced, if assisted by a very gentle agitation, the atoms, constituting the particles at the surface, will rush very near together, as at A, *fig*. 37 ; hence a quantity of caloric and electric fluid will be discharged from between them, on the exterior side towards A, into the air at H and K, and on the interior side towards B; this last, and the caloric rising from the liquid, will tend to separate the atoms from each other at B; and as the egress is prevented at A, the ethereal matter must find its passage from the interstice B, by *n* and *m*, through H and K, separating the particles there, and greatly facilitating an arrangement at L and M, similar to that at A ; and it is evident, that as the ethereal atoms (the caloric and elec-

tric fluid) continue to rise from the interior, a symmetrical arrangement will be produced; for instance, that ethereal matter, which flows from C and F, must pass by *p* and *q* into B and G, thence in part by *m* and *r* to K, in this case producing a continued series of regular hexagonal figures, and lines of particles as AP and LQ, crossing each other at angles of 60° and 120°; and the atoms may be such, that the volume shall be increased by means of the pores formed at B, C, and F, G, &c. The expansion depending chiefly on the extent of the spherules of the atoms which compose the particles, and may be such as to increase the volume $\frac{1}{8}$, as found by experiment.

Obs. This figure is only a section of the liquid formed into ice, but L, A, and M, may be considered, as the apices or summits of regular tetraëdra: thus L*xw* will represent one face of a tetraëdron, and conceiving another line, similar to L*x*, or L*w*, to proceed from L to the base, it will form with L*x* and L*w*, the two other faces, the fourth being that base, hence the tetraëdron will contain twelve particles; and consequently, twelve atoms of oxygen and twenty-four of hydrogen. The same figure may be considered as an horizontal section, and then each of the equilateral triangles, such as L*xw*, will represent the base of a tetraëdron, the summit of which must be supposed vertically above the middle of the equilateral triangle, L*xw*, &c. The same may be observed of three contiguous groups, as those whose centers are *w*, *y*, *z*, four of these groups form a rhombus, *wyze*, and evidently a solid, so constituted, will be divisible in some directions more easily than in others.

A different arrangement of the same particles might have been given, such that they should still cross in angles of 60° and 120°; but that which is figured seems to me the most probable arrangement.

The solidity of the body arises from the approximated, and consequently fixed position of the particles round the centers, such as the six particles around *w*, the centers of the oxygen forming the angular points of a regular hexagon; and the increase of volume arises from the expanded pores at B, G, &c. The same arrangements will be preserved in accumulated masses; thus APR will form the base of a larger tetraëdron.

Ph. 28. When large masses of ice, two or three inches thick, are formed on the surface of standing water, they are crystallized, and all the axes of the elementary crystals, correspond with the axes of hexaëdral prisms, being exactly parallel to each other, and perpendicular to the horizontal surface.

Exp. If *fig.* 37 be considered as an horizontal section, a little attention will shew, that *w*, *y*, *z*, &c. are in the axes of such prisms, formed by the six particles immediately surrounding them, and any one of these axes is also the axis of more extended hexaëdral prisms; thus the axis passing through *y*, perpendicular to the horizon, is the axis of a hexaëdral prism, one of whose sides is A *v*, and *v* Q forms a part of the adjacent side; hence the explanation (*ph.* 27.) of the formation of ice, agrees with the fact here specified.

Ph. 29. Water freezes at the temperature of 32° Fahr. but may be cooled down as low as 22°, if kept perfectly still; but if, while the temperature is below 32°, it is gently agitated, it freezes immediately, the temperature rises, and becomes 32°, which also happens, if only one point on the surface of the liquid be touched.

Exp. This is what ought to take place, and is a fact we might expect, as will evidently appear from the explanation of *ph.* 27; for while the liquid is perfectly still, the ethereal atoms escape uniformly on all sides of the particles of

the fluid, and the liquid state is not changed so soon as otherwise, but if while at a temperature below 32°, it be gently moved, or even touched at some point of the surface, some of the atoms, already in a condition to unite, will by the commotion take the position represented at A, *fig*. 37, as stated in the explanation of *ph*. 27, where it is shewn, that this circumstance promotes a similar position in the neighbouring parts, as at M and L, and at the same time discharges into the adjacent pores much ethereal fluid, which consequently, tending to escape, raises the temperature to the freezing point, *viz*. to 32°, at which point it remains, and gives out caloric, and electric fluid, the whole time of freezing; and evidently, that particular point, rather than any other, depends on the forces and extent of the spherules of the oxygen and hydrogen which compose the particles of water.

Ph. 30. In general, liquid bodies, which by cooling become crystallized, undergo an expansion when they assume the solid form, but those which do not crystallize, contract, and there is a certain temperature, different for each, at which they become solid.

Exp. This will arise from the difference of the atoms or particles composing the fluid, as will be fully evident from a consideration of the two last explanations. When the body crystallizes, the expansion takes place, but when otherwise, the body continues to contract till it takes the solid form.

Ph. 31. Liquids, during their conversion into the solid form, give out much caloric, without decreasing the temperature of the solid; and conversely, solids during liquefaction absorb much caloric, without increasing the temperature; a circumstance analagous to the change of gases to liquids, and liquids to gases.

Exp. These important facts are explained in a similar

manner to the analagous ones in phenomena 25 and 26: they were first clearly ascertained by Dr. *Black*, and are universally admitted, but I do not know that they have hitherto received any satisfactory explanation, so that with some confidence I offer those explanations referred to above, to the consideration of the philosopher.

Ph. 32. What is said of gases in general, in some of the preceding phenomena, applies equally to vapours, provided the pressure and temperature be such, that no part of the vapour is converted into a liquid form.

Exp. Here the same explanations hold good; for under these restrictions, the vapours possess the characteristics of permanent gases.

Ph. 33. When part of the vapour, from the increased pressure, or diminished temperature, or from both these causes, is reduced to a liquid form, the elasticity does not increase as the pressure; and the other phenomena relating to gases in other cases, are modified in this.

Exp. For since the part of the vapour condensed is deprived of the ethereal matter which renders it gaseous, it loses its elasticity, and therefore no longer acts according to the same laws.

Ph. 34. Liquids under the same pressure, other circumstances being the same, are converted into vapours at the same temperature, for each separate liquid of one kind; but at different temperatures for each different liquid, and the converse.

Exp. There is no reason why the temperature should be different for the same liquid; and the difference of the atoms or particles will account for the different requisite temperatures of different liquids.

Ph. 35. The nature of the vessel containing the liquid, or of substances introduced into it will make a difference

in the point of temperature at which the vapour is formed.

Exp. For the difference in the materials of the vessel, or substances introduced, must have, from the difference of their component atoms, different powers of retaining or transmitting the ethereal atoms, which sufficiently accounts for the phenomena.

Ph. 36. The same liquid under a greater pressure, other circumstances being the same, requires a higher temperature to convert it into vapour, and the converse.

Exp. Evidently a greater force under an increased pressure is required to cause the ethereal matter to gain access to, and form atmospherules on, the atoms or particles of the liquid, in order to convert them into the gaseous form, and the converse.

Ph. 37. If a portion of liquid be contained in a vessel, as AB (*fig.* 38) at a given temperature, and under the greatest pressure P, at which the vapour can be formed at that temperature, the liquid will be all converted into vapour; after which its greatest volume will be attained; but if, at any stage of the process, the pressure be increased by a very small quantity, the conversion of the liquid into vapour will cease, and the volume will remain as it is at that period: and if the pressure be still further increased, the vapour will be again converted into a liquid form.

Exp. The preceding and the 32nd phenomena, being admitted, this requires no further explanation.

Ph. 38. If as above AB (*fig.* 38) contain a liquid, of which a portion is converted into vapour, and the pressure P is exactly that which preserves the equilibrium, that is under which the liquid is not converted into vapour, nor the vapour into the liquid form; and if CD (*fig.* 39) be filled with other gas, or vapour, of a different kind, but at the

same temperature, and under the same pressure; and if now a communication be made between the two elastic fluids, provided they be such as in this form do not unite chemically so as to form new compound particles, they will be mixed together, uniformly, and the whole bulk will remain the same.

Exp. If AB contain no liquid, this will be the same as *ph.* 22 and 24, and therefore the uniform mixture will take place. Now during the time of mixture, suppose the volume to be kept unaltered, the same force will remain, for it cannot increase without condensing a portion of the vapour, nor diminish without admitting the formation of more vapour, hence the volume remains the same.

If some of the gas be absorbed by the liquid, the pressure will be lightened, and hence more vapour will be formed, so that the equilibrium will still be maintained.

Ph. 39. If a portion of dry gas, of a given temperature, be placed over water at the same temperature, and the pressure be given; the air will become mixed with vapour, and the volume will increase by a space which steam, at the same temperatnre, and under the same pressure would occupy in a vacuum.

Henry's Chem. vol. i. p. 257. *Thompson's* Chem. vol. iii. p. 38.

Exp. Under these circumstances a thin stratum of vapour will form at the surface of the liquid, this will mix with the gas according to the foregoing explanations, hence other vapour will form in like manner at the surface and mix with the gas, and thus the process will continue, till the force with which the vapour tends to form at the given pressure, and temperature, together with the force of the gas, is exactly a counterpoise for the pressure, and hence, the sum of the volume is the same as it would be,

if both the gas and vapour were separately subjected to the same pressure.

Hence if the volume of gas $= 1$, $p =$ the pressure, and the temperature such, that $f =$ the force, or the pressure which would exactly preserve the vapour in its form, then the vol. $= \frac{p}{p-f}$.

Ph. 40. The density of steam is proportional to its elasticity, or nearly so.—*Henry's* Chem. vol. i. p. 122.

Exp. Let the vapour be contained in the vessel AB (*fig.* 38.), and conceive the pressure P to be increased gradually, and also let the temperature at the same time be increased, likewise gradually, and just so much as barely to prevent the vapour from assuming the liquid form, while the pressure preserves it under the same volume; now it is evident that the density is continually increased, and that the elasticity is always equal to the pressure; also the caloric extricated by the pressure, together with that which is supplied by the increased temperature, is but just requisite to support the liquid in the form of vapour, and hence the condition of *phenomenon* 17 is obtained, and the contraction, and consequently the density, will be as the pressure, and as the elasticity.

Ph. 41. All kinds of gases, of equal volume, and under equal pressure, if made as free as possible from moisture, and placed over water previously saturated with the gas, the temperature being given, will imbibe an equal quantity of vapour from the water.

Exp. This follows as a necessary consequence from the 38th *phenomenon.*

Ph. 42. Gases are variously absorbed by liquids, and by porous and divided solids.—*Henry's* Chem. See *ph.* 26. *sect.* v.

Exp. This is a natural consequence from the theory; for the particles of the gas, applied to the surfaces of the porous bodies, will be attracted and consequently imbibed.

Ph. 43. When bodies are all of the same temperature, and free from the action of the radiant matter of other bodies; there is no appearance of the transmission of radiant matter from the one to the other.

Exp. For the equilibrium of temperature arises from the balance of the repulsive forces of the caloric contained in the bodies, and since this repulsion is the cause of the radiation, the bodies must cease to radiate, or if they radiate in consequence of vibrations, they must receive as much caloric as they give by radiation, and hence the effect is not apparent.

Ph. 44. When bodies are of different temperatures, caloric will be observed to leave the one and enter the other.

Exp. Evidently the resistance to the projection of caloric is less, when the temperature of the neighbouring bodies is lowered, hence the caloric radiates by the repulsion of the spherules, and this is promoted by the vibratory actions produced.

Ph. 45. When bodies are of a much higher temperature than the surrounding ones, abundance of caloric issues from them with immense velocity in a radiant form.

Exp. When bodies are in this state, their ethereal atoms are crowded closely together, the centers of each being deeply pressed into the spherules of the others, and many of them into those of the tenacious atoms, hence the restraining force being removed, the caloric is propelled with great velocity; and the consequent vibratory motion produced in the bodies, contributes very much, in its turn to promote the same effect by impelling successively the atoms nearer to each other.

PH. 46. When the hot bodies attain a certain temperature, they radiate light as well as heat.

Exp. The preceding explanation applies here, being common for all ethereal matter, varying in degree according to its nature

PH. 47. Radiant matter projected from hot bodies, is copiously reflected at some surfaces, refracted at others, and absorbed at a third sort of surfaces.

Exp. When the surface, on which the radiant matter falls, consists of particles lying closely together, and covered by ethereal matter, the radiant matter will be copiously reflected; but when the particles are uniformly situated, touching at certain points only, and enveloped by distinct atmospherules, abundance of ethereal matter will be refracted, while some is reflected; when the particles are irregularly placed, and not connected but at certain points, the greater part of the ethereal matter falling on them will be absorbed.

PH. 48. The nature of the surface of a body, has an important influence over its power of radiating caloric: thus the radiation is less from polished tin, than from the same tarnished or scratched, and still less than when it is painted black.

Exp. This agrees with the theory, as appears from *prop.* 17, and its *cors. sect.* ii. for the asperities will contain accumulated ethereal matter, from which it will be most readily projected, and by their means also a more powerful vibratory commotion will be produced.

PH. 49. Caloric passes with different degrees of facility and quickness through different bodies, which are on this account called better or worse conductors of caloric.

Exp. When the tenacious atoms of the body, have small force and extensive spherules, the ethereal matter will pass rapidly among them; also when the tenacious atoms

have great force and small spherules, and are closely united in a dense body, so that its ethereal matter is diffused and uniformly spread over the surface, that surface will admit a ready, and uninterrupted passage for the ethereal matter: bnt when the particles of a body are connected firmly in some parts only, as in some solids, or loosely connected as in liquids, so that the ethereal matter forms on the particles distinct dense atmospherules, the body will oppose a powerful obstruction to the progress of caloric, or other ethereal matter, more or less according to the forces and spherules of that matter, and the velocity of projection.

PH. 50. Gases and liquids, when there is no interchange of their parts, are much worse conductors of caloric than solids in general,

Exp. This follows on account of their more distinct and separate atmospherules, as appears by the preceding phenomenon.

PH. 51. Liquids and solids expand when the temperature is raised, and contract when it is lowered.

Exp. The explanation is the same as for the similar effects on gases, (*ph.* 20), but here the ratio of expansion varies because of the connection of the parts.

SECTION V.

Phenomena relating to Cohesion, Repulsion, and Crystallization.

Cohesion, or cohesive attraction, is that power by which the parts of bodies are held together, that which gives the globular form to drops of liquids, and their greater or less firmness to solids. It is usually said to act only between adjacent parts, and where there is no matter to prevent immediate contact; but, as Sir *H. Davy* has well observed (El. of Chem. Phil. page 63), the spherical form of small portions of liquids is preserved by the mutual attractions of the several parts, proving that the cohesive power is exercised at sensible distances.

Although it has frequently been surmised, that cohesion is only the general power of gravitation modified, yet the most prevailing opinion is, that it varies by a different law, *viz.* that of the inverse ratio of the cube, or some higher power of the distance. This opinion is founded on the 75th *prop.* of the Principia, book 1st. and the proof of this proposition rests on the 70th and 71st, two very elegant theorems in the doctrine of forces, but inapplicable in the particular case of *prop.* 75. It appears to have been an oversight, and it is somewhat remarkable that it has not been noticed long ago; for it is obvious, that the

hypothesis of *Newton* requires, that the forces should be directed to *every point* of the spherical surface, or of the sphere; now it is universally admitted, and on the *Newtonian* principles, that bodies contain more vacuities by far than solid parts, and if the forces were directed to a great number of points, symmetrically arranged in a physical spherical surface, but not to every point in that surface, it would be easy to prove, that a material point, from certain places within that surface, would move towards the center, and from others towards the adjacent attracting points; hence the attraction of an atom, placed in contact with one of those in the surface, would be greater than that of the whole of the remaining part of the surface to that atom, and hence, if separated to a small distance, the attraction would apparently cease.

But from other considerations, the same may happen; thus, if we admit the ingenious and admirable theory of *Boscovich*, which supposes several alternate spheres of attraction and repulsion to have place within a small distance from the centers of each atom, we shall have this consequence, that if an atom or particle be removed from contact with a body, not only will it cease to be attracted, but repulsion will ensue. However, that this effect may be produced, it is not necessary to suppose the actual existence of these different alternate spheres of attraction and repulsion, the same phenomena will necessarily occur, if we suppose that a certain substance consisting of material atoms, which we denominate caloric, light and the electric fluid, diffuses itself over the surfaces of the atoms, of which bodies are composed; for, the intervention of this will counteract the attraction at a very small distance; thus when a piece of glass is broken, the cohesion does not again take place when we put the pieces together, not only because we cannot bring them so near as before, but

also, because ethereal matter has diffused itself over the separated surfaces.

We frequently perceive an apparent repulsion between bodies at sensible distances, but these cases traced to their source, shew that they are only modifications of a repulsion between atoms in close connection, or that repulsion which occurs, when ethereal matter escapes suddenly from an atom, or suddenly enters it, or from the occurrence of both these circumstances, (see *prop.* 14. *cors.* 9, 10, and 11.) such repulsions are often observed, when cohesion is destroyed, or produced in bodies.

The elasticity of solids, and crystallization, are also connected with cohesion, sufficiently to admit of introducing the phenomena relating to them under the same head. "The power of cohesion," saith *Goldsmith*, "by which bodies are held together, has perplexed the philosophers of "every age, and every age has attempted the solution." The attempt made in this section is different from any which has been offered to the public, and will probably be found to contain the true explication of this universal power, the same with the attraction of gravitation.

When the particles of bodies being in a liquid form are placed in contact, then if the atmospherules intermix, which must very frequently happen, or when the particles of the same body in a liquid form, have atmospherules so rare, that the tenacious atoms can come near each other; then will these particles cohere or stick together, as is manifest from the theory, and from what has been shewn in similar cases.

Ph. 1. The parts of bodies which are in the liquid form, as water, quicksilver, &c. cohere, or stick together, as is evident from the globular figure, which they assume when in minute partions, this is also seen from the uniting of two or more drops into one.

Exp. The cohesion will evidently result from the theory here proposed, and hence the above fact requires no further elucidation.

Ph. 2. If a vessel of glass, porcelain, metal, &c. have a thin stratum of water on its flat bottom, and if a drop of alcohol be placed, by means of a glass rod, nearly on the center; a dispersion of the water is produced, leaving the bottom of the vessel dry :—the edge round the alcohol presents an undulating or tremulous motion, shewing the continual emission of the particles of alcohol to the water, till they are united. This is most evidently seen by varying the experiment, first using water tinged by turnsole, and then using alcohol similarly tinged. *Nicholson's* Jour. vol. viii. p. 20.

In this experiment we perceive a repulsion and a subsequent union.

Exp. When liquids of different composition are put together, an easy deduction from the theory will shew, that in many cases a part of the atmospherules of the one fluid will pass over to those of the other, and in the present case a portion of the atmospherules of the alcohol being transferred to those of the water, will cause the dispersion of a thin stratum of that liquid, (*prop*. 14. *cor*. 9. *sect*. ii.) and after the equilibrium of the atmospherules is attained, the mixture will be effected, and the parts will either cohere or enter into chemical union.

Ph. 3. If reversing the order, the alcohol be put on the flat bottom of the vessel, and a drop of water placed on it, as above, the alcohol is not dispersed, but the drop of water flattens, and spreads irregularly, and mixes with the alcohol.

Exp. The ethereal atoms, issuing from the alcohol, will support the drop of water bearing it up by the repulsive

force between the atoms in leaving the one and entering the other, till the effect is produced.

Ph. 4. A variety of similar instances are observed to take place with other liquids.

Exp. These depend on the same principles, and require the same explanation.

Ph. 5. Some liquids mix very readily.

Exp. This will depend on the liquids, and the mixture will be effected according to the suitableness of the particles, and their atmospherules for that purpose. (*Prop.* 14. *cor.* 11. *sect.* ii.)

Ph. 6. Some liquids do not readily mix, as oil and water.

Exp. We have here only to observe, that if the tenacious atoms of each liquid retain their atmospherules with such force, that they do not pass from the one to the other, (*prop.* 14. *cor.* 11. *sect.* ii.) the union will consequently be prevented.

Ph. 7. In some cases liquids readily stick to solids, as water to glass, and mercury to gold, silver, &c.

Exp. This must take place, when a portion of the atmospherules of the particles of one body readily passes to the other, and hence a close connection of their atoms will ensue, the force of the tenacious atoms being sufficient to displace in some degree the ethereal matter.

Ph. 8. In some instances liquids do not stick to solids; thus mercury does not stick to glass or to iron, &c.

Exp. This must take place when the particles of each body firmly retain their own atmospherules, and hence the tenacious atoms cannot come into contact, being so far separated that they cannot displace the ethereal matter.

Ph. 9. Various solids in a state of minute division, as sand, ashes, powders, &c. will readily stick together,

when wetted with water, or various other liquids, but not when dry and warm.

Exp. When such bodies are dry and warm, their surfaces retain much ethereal matter, particularly caloric, which prevents their junction; but water absorbing a considerable quantity of this caloric (as in *ph.* 2.) sticks to the surfaces and suffers them to come into union with facility.

PH. 10. If a firm body, as a piece of glass, be broken, and the pieces carefully put together, they do not in general unite even when great mechanical pressure is employed.

Exp. Soon as the contact is broken the ethereal atoms because their centers are in each other's spherules, are diffused over the surface (*prop.* 17. *cor.* 9. *sect.* ii.) and this prevents the re-union.

PH. 11. Most solid dry bodies may be reduced to powders by trituration.

Exp. This follows from the explanation of *ph.* 9 and 10; for as the bodies are broken by grinding, pounding, rubbing, &c. the several parts have their surfaces successively surrounded by ethereal atoms, which prevents their consolidation, hence they remain in the state of powder, or in such pieces as those into which they have been broken.

PH. 12. Bodies cohere with different forces: thus to break a wire $\frac{1}{10}$ of an inch in diameter requires for gold $299\frac{1}{4}$*lb.*, for iron 450*lb.*, for lead $29\frac{1}{4}$*lb.*, the weight being hung on it so as to press it in the direction of its length, and thus also different sorts of wood, cord, &c. require different forces to separate their parts.

Exp. This will be a natural consequence from the composition of bodies according to our theory, and

this difference will depend on the force of the atoms, and the manner in which the particles are applied to each other.

PH. 13. In general it is observed, that the bodies stretched as above become somewhat longer before they break.

Exp. This will be evident from *prop.* 9. *cor.* 7. *sect.* ii. which shews the reason of this fact.

PH. 14. If the surfaces of two leaden balls be finely planed, and closely pressed together with a slight twist, they cohere with great force ; Mr. *Martin* says that it required 150*lb.* to separate two such balls, not touching in more than $\frac{1}{10}$ of a square inch of surface; and evidently, the pressure of the atmosphere can have but a very small share in producing this effect.

Exp. When the atoms which compose a body are so constituted as to their forces, and the extent of their spherules, and the manner of their union, that by a certain degree of pressure, the parts of two such bodies can be squeezed close together, so that the atmospherules of their atoms may intermix, this cohesion ought to take place, and such seems to be the composition of lead; in the same manner the parts of moist clay and various other bodies may, being applied to each other, adhere and form one mass.

PH. 15. Various bodies, such as glass, marble, metals, wood, &c. having their surfaces made perfectly plane, will adhere with different forces, and certain other substances, put between, will increase the cohesion, less or more, according to the nature of the body interposed, being greater with oil than with water, and still greater with tallow, pitch, &c. Thus two surfaces each one square inch, will adhere with a force of nearly 200*lb.* when only half a

grain of tallow is introduced between them. The union of bodies by soldering, gluing, &c. depends on this principle.

Exp. But little of this is due to the pressure of the atmosphere; the particles when near, attract each other with great force, and when the parts of the interposed body can come into close union with the surfaces, this ought to take place as stated in *ph.* 9, and 14, of this section.

PH. 16. When the fragments of certain bodies, as the filings of metals, pounded glass, rosin, &c. are melted, and suffered to cool, they enter into a solid form.

Exp. For, by fusion, the atoms of the body are equally diffused, so that the whole becomes a liquid whose parts cohere, and on the removal of the caloric, a gradual approach is admitted, and a solid mass formed according to what was shewn in *ph.* 27, 28, and 29, of the 4th *section.*

PH. 17. Solids possess different degrees of hardness, and flexibility.

Exp. This will arise from the differences in the constituent particles, and from the different manner of their union in forming the body, from which every variety of this kind may arise.

PH. 18. Liquids will in some cases rise on the sides of solids immersed in them, as water on glass, &c.

Exp. When the liquid can stick to the solid as in *ph.* 7, it will rise to the adjoining upper stratum of atoms in the solid by attraction, and the cohesion of the liquid (*ph.* 1st) will elevate and support the contiguous strata of the liquid; in like manner the upper stratum of the liquid will again be attracted and adhere to the next higher stratum of the solid, bringing up and supporting more of the liquid, and so on till the quantity supported is a counterbalance to the force by which the two substances tend to cohere;

and hence the elevation will depend on the force tending to unite the two bodies, and the weight of the liquid jointly.

PH. 19. Some liquids are depressed on the sides of solids as mercury on glass, &c.

Exp. When the liquids do not stick to the solids, as in (*ph.* 8.), the atmospherules of the atoms of the two bodies prevent their union, and the particles of the liquid cohering together (*ph.* 1.) will keep them united; hence the liquid will exhibit on one part a convex surface, leaving a space between the liquid and solid to such a depth, as will depend on the force of the atmospherules keeping them separate, and the weight of the liquid jointly.

PH. 20. Water and several other liquids rise in capillary glass tubes to altitudes inversely as the diameters, thus water will rise an inch in a tube of $\frac{1}{30}$ of an inch in diameter, and half an inch in a tube of twice that diameter; sweet oil will rise about half that altitude.

Exp. Since the liquid rises by the action of the stratum or line of atoms in the solid immediately above the liquid (*ph.* 18.), the force of that action is given, and the quantity raised will therefore be as the circumference of the tube, that is, as its diameter; but the quantity raised in the tube is also as the altitude and the square of the diameter jointly, (*geom.*) therefore the altitude will be (as the diameter directly and the square of the diameter inversely, that is) as the diameter inversely.

On the same principle liquids rise between parallel planes, and into porous, spungy, and fibrous substances.

PH. 21. Mercury is depressed in a glass capillary tube, and the depression is inversely as the diameter of the tube.

Exp. For the quantity of mercury requisite to bring the liquid and solid so into contact, and into a state of

equilibrium, that there shall be no further depression, will depend on the force of resistance between the solid and the contiguous atoms (*ph.* 19.), and the liquid being given, the number of these atoms is as the circumference of the tube; therefore the proportion mentioned must be the consequence, as was explained in the last phenomenon.

A great variety of phenomena depend on the same principles.

Ph. 22. When two small balls, or other bodies, float on a liquid, which adheres to them both; when placed at a small distance, they will approach each other with an apparent attraction, and with an increasing velocity.

Exp. Since the liquid rises on every side of both the balls, there will be more liquid elevated in the part between them, than on either side; hence the liquid to produce the equilibrium will flow towards that place from which the most liquid has been raised, and carry the balls with it, making them approach with an increasing velocity.

This attraction is therefore only apparent; the true cause being the action between the bodies and the liquid, in the place of nearest contact.

Ph. 23. The same apparent attraction takes place, when the liquid does not adhere to either of the bodies.

Exp. Here there is a depression of the liquid on all sides, so that it is more depressed between the bodies than on other parts, and the liquid of the vessel, flowing towards the part where most has been removed will, in this case also, force the balls along with it towards each other with an accelerated motion.

Ph. 24. When the liquid adheres to one of the bodies, but not to the other, there is an apparent repulsion.

Exp. Here the liquid is raised on one ball and depressed on the other. Now the liquid depressed on the

part between them, on the one ball, rises on the interior of the other; hence there is not so much liquid displaced by the depression and elevation between them, as there is on each of the opposite sides; and hence the liquid will flow from the parts between them towards both the opposite sides, and carry the balls from each other, producing an apparent repulsion.

Sch. From the three preceding explanations, it follows that the apparent attraction and repulsion of floating bodies, depends on the contiguous attractions and repulsions between the liquid and solid bodies.

PH. 25. Porous bodies such as charcoal, sand, &c. absorb different quantities of different liquids.

Exp. This is in consonance with the theory as appears from the foregoing explanations.

PH. 26. Porous bodies absorb different quantities of different gases, and, by exposure to heat, give them out unchanged.

Exp. That such bodies should absorb different quantities of dissimilar gases will follow from the different forces and extent of the spherules of the atoms composing the gases, and from their more or less extensive atmospherules; and that heat will expel them unchanged follows from this, that the atmospherules of both the solid and the gas are extended by the increased heat, and the cohesion between the solid and the gas is diminished; hence the gas is expelled unchanged, from the pores of the solid, now to be occupied by caloric.

PH. 27. Many solids may be dissolved in liquids, and hence their cohesion is destroyed; thus many salts may be dissolved in water, &c.

Exp. In this case the attraction between the atoms of the liquid and solid is sufficient to bring one of the former between two of the latter and thus to destroy their union;

and hence the particles of the solid now adhere to those of the liquid with greater or less force, and are soon diffused through the liquid on the same principles as shewn in *ph.* 22. *sect.* iv. respecting different gases.

Ph. 28. When the liquid is gently withdrawn by evaporation, the particles of the solid will generally unite in regular forms called crystals.

Exp. When the solid is a compound body, that is a body consisting of particles formed by the union of different atoms, the attractions of these particles will be greater on one side than on another, and will therefore possess a kind of polarity (*prop.* 15. *cor.* 4. and *prop.* 16. *cor.* 5. *sect.* ii.) and hence when at liberty they will take a symmetrical arrangement, as shewn in the freezing of water, (*ph.* 27. and 28. *sect.* iv.) and when the formation of the solid is commenced, a particular manner of increase will be promoted by the extension of ethereal matter more at the angular points than at the edges, and more on the edges than on the flat surfaces, (*prop.* 17. *cor.* 9. *sect.* ii.) this last will be the chief cause of crystallization in the case of simple bodies, and hence with these it is not so common as in compound bodies.

Ph. 29. If the process of evaporation be slow and undisturbed, the crystals will be produced with great regularity; but if it be rapid and not tranquil, the crystals will be irregular and confused.

Exp. This will happen, because in the first case, the particles are at liberty to take the regular arrangement to which their forces direct them, but in the second case, this freedom is interrupted.

Ph. 30. Crystals are bounded by plane surfaces.

Exp. It will follow from *ph.* 28. of this section and from *prop.* 17. *cor.* 9. *sect.* ii. that a row of atoms will most readily form along the angular edges of the nucleus,

or on the stratum or line of atoms next to the angular edges, and hence rows will be added over the whole surface in adjoining layers, which will produce the effect, and present regular bodies with plane surfaces.

Ph. 31. Crystals may be split into thin smooth plates in some directions, but when broken in other directions, they present an irregular fracture.

Exp. This will naturally arise from the uniformity of the disposition of the particles in the act of crystallizing; see *sect.* iv. *ph.* 27, 28 and 29, which explains the formation of ice, or the crystallization of water.

Ph. 32. If crystals be split in the directions of easy and even cleavage, a particular nucleus is ultimately attained, and this is denominated the primitive form; *Haüy* thus obtained six primitive forms; *viz.* 1. The cube. 2. The tetraëdron. 3. The octoëdron. 4. The hexangular prism. 5. The rhombic dodecaëdron. And 6. The dodecaëdron with isosceles triangular faces: and these six may mechanically be reduced to three integral elements, *viz.* 1. The parallelopiped, having six surfaces parallel, two and two. 2. The triangular prism. And 3. The tetraëdron.

Exp. From the simple nature of atoms it is to be gathered that the primitive forms of crystals should be few and simple, such as may be produced by a connection of spheres, or spheroids, for compound atoms will generally take the forms nearly allied to spheroids.

Ph. 33. The same body always tends to crystallize, so as that the crystal shall have the same primitive form.

Exp. It must be expected while we admit the foregoing explanation, that the same kind of particles will take the same kind of arrangement; and this will consequently produce the same primitive forms.

Ph. 34. That the same body is found crystallized in va-

rious forms, these are called secondary forms, and may by proper cleavage be reduced to the primitive ones.

Exp. For owing to an extension of the atmospherules on the angular edges, and points; under certain circumstances decrements of the layers will take place along the edges, or at the angles, which will occasion the great variety observed in nature, respecting crystals of the same substance.

PH. 35. Under the same circumstances, the same crystalline forms are produced, but modifications take place from various causes, as, differences in the solvent, different proportions of the ingredients of the body in solution, the action of light, electricity, &c.

Exp. This is a natural result from the theory, for these circumstances give particular directions to the uniting atoms.

PH. 36. If different bodies, capable of crystallization, be dissolved in the same liquid, and the liquid is left to evaporate very slowly, by spontaneous evaporation; it will frequently happen, that the crystals of the different bodies will be formed separately, and thus they may be obtained apart.

Exp. Owing to the different forces and atmospherules of the crystallizing substances, some will crystallize at a different stage of the evaporation to that at which the others will unite, and this will account for the fact.

PH. 37. Crystals, and other bodies having angular points, and edges, will, if exposed to the action of other substances, be defaced sooner at those angular parts than at the parts which are more flat or round.

Exp. A little attention to *prop.* 17. *cor.* 9. *sect.* ii. will fully shew the reason of this fact, the parts are separated here very readily because of the slender cohesion, and the great quantity of ethereal matter pressing there.

Ph. 38. Solid bodies contract by the abstraction of heat, and expand by increased temperature.

Exp. For the ethereal atoms which constitute heat, accumulating in the pores and about the tenacious atoms of the body, produce an expansion, and the withdrawing of these, a contraction in the volume.

Ph. 39. Metals, and such bodies as will yield in a certain degree to the stroke of the hammer, are rendered more dense, and often more hard and fragile by hammering.

Exp. This operation must tend to bring the atoms nearer together, and to exclude a large portion of ethereal matter from them : hence, although the force of cohesion will be increased, the flexibility of the body will be impaired, and evidently the density will be augmented.

Ph. 40. The cohesion of metals is greatly increased by hammering and by drawing them out into wire.

Exp. For by these operations the tenacious atoms are brought nearer together, and part of the ethereal matter is expelled, and hence the effect is produced as noticed above.

Ph. 41. By hammering, the temperature of metals is raised, in some cases very considerably; thus soft iron, though cold as ice, may be rendered red hot by this process, if dexterously performed.

Exp. As the tenacious atoms are forced nearer together, a considerable quantity of ethereal atoms must be expelled, more or less according to the circumstances, and evidently much more in soft iron than in hard, and the rapid escape of the caloric produces the heat.

Ph. 42. Several bodies when melted, and suffered to cool rapidly, inclose a large quantity of caloric. Thus if a considerable body of cement, composed of rosin, bees wax, and red ochre, be boiled up in an earthenware pot,

and set to cool, it is found, when the surface is so far cooled that it may be handled, that if the surface be broken the heat of the interior part will again produce ebullition, and the boiling will continue till the surface is cooled, and again so far consolidated as to stop the process, which may be renewed a second time. Also a lump of liquid glass, when apparently almost cold, so that it may be safely handled, if broken, will be found red hot at the central parts, and continue so for several hours. *Parke's* Chem. Essays, vol. iii. p. 419.

Exp. In such cases as these, the tenacious atoms of the melted body, uniting at the surface, where the caloric is rapidly dissipated, form a crust, or solid surface, opposing the extrication of the internal heat by means of the adherence of ethereal matter to this external coat: and it is plain, that, in many cases, a portion of heat will be permanently inclosed, more than if the body had been cooled down slowly.

Ph. 43. Some red hot bodies by being quenched in cold water, or suddenly cooled, become harder and more brittle; iron and steel afford well known examples.

Exp. In these cases the atoms of the surface in cooling unite, and inclose a portion of caloric, as in the last phenomenon; the sudden cooling is the means of bringing the atoms, their forces and spherules admitting it, closer together than otherwise they would have been, which renders the body harder, and the quantity of caloric enclosed, and even compressed, within the body, renders it more brittle: for when the outward thin crust is broken, it readily snaps asunder by the evolution and bursting forth of the caloric at the fracture.

Ph. 44. Some bodies which are somewhat hard and brittle, as copper-wire, &c. become more soft and flexible by being made red hot, and quenched in water.

Exp. In this case, the atoms of the outer surface do not immediately and closely unite, so as to prevent the internal caloric from flowing through it, but only so much as to give it a slow and regular passage; and hence, by the heat, the atoms of the body are made to assume a position more distant and uniform than that which they had before the operation, and the body is therefore made softer, and more flexible. The difference between this fact and the preceding, is readily accounted for, by admitting a slight difference in the extent and force of the constituent atoms of the body.

Ph. 45. Some solids are hard and brittle.

Exp. This will happen either when the atoms of the surface are in firm contact, and union, while the interior parts contain ethereal atoms in a compressed state, as in *ph.* 43, or when the particles of the body throughout are united firmly in but few points, which may occur in a multitude of cases.

Ph. 46. Some solids are soft and inelastic.

Exp. This must occur when the atoms, or particles composing the body, are but slightly united in many points; the cohesion being feeble, and easily yielding either way to a slender force applied.

Ph. 47. Some solids are very elastic, as well-tempered steel, ivory, glass, &c.

Exp. This, the atoms of the body being of a suitable kind, will be the consequence of an arrangement intermediate between those noticed in the two foregoing cases; but because the elasticity of solids has never yet received a satisfactory explanation, I shall be a little more particular.

Let AB, EF, and CD, (*fig.* 41. *plate* II.) represent three rows of atoms in one plane, making part of a body, bent from a straight line to a curve. Now, by the act of

bending, the centers of the atoms on the concave side in AB are brought nearer, and therefore more into the spheres of each other's repulsion, while those on the convex side, CD, have their centers removed more distant in the sphere of each other's attraction. Hence, there is produced a force of attraction on the convex side, and of repulsion on the concave, both tending to bring the bent solid to its state of equilibrium, as in its former position and figure, and since there is an innumerable number of forces on both sides, and all tending to promote the same effect, the figure is restored in many cases with very great energy; for although in this instance, only three rows of atoms are represented, yet in nature there are an innumerable multitude of such rows. It will be observed, that the effect of the repulsion on the concave side will be much greater than that of the attraction on the other side, because as the centers separate on the convex side the attraction diminishes, but as they approach on the concave side, the repulsion immensely increases, because of the very small distance.

"The major part of the philosophers, who have attempted to give a theory of elasticity, have especially considered, that when an elastic body is bent, for example to an arc, the particles situated on the convex side, become further separated from one another, while those, which are on the concave side approach each other. But of all the causes on which the re-establishment of the body in its first state has been made to depend, such as attraction, the resistance of a particular subtile matter diffused between the moleculæ of bodies, the action of caloric, &c. there is not any which is conducive to a satisfactory explanation of the phenomena."—*Haüy*.

Of this wonderful and hitherto puzzling phenomenon, the reader is now presented with another explanation, which, it is presumed will prove satisfactory to the phi-

[illegible], it being natural and in unison with the circumstances of the action.

PH. 48. If a slender piece of steel be made red hot, and quenched in cold water, and if afterwards a gentle heat be applied till its temperature be sufficiently raised, it will be elastic, and form a spring.

Exp. By making the steel hot, and quenching it in water, it is rendered hard and brittle, as in *ph.* 43, the atoms of the surface are brought close together, and the body will break by the least fracture of the surface; but by gently heating it, the atoms composing the surface, are in a small degree removed farther apart, and some portion of the inclosed ethereal atoms are diffused among them; when this is carried to a certain point, a slight bending will not separate or break the surface, and it becomes fit for a spring by attaining the conditions of the last phenomenon. If the hardened steel be made too hot, the atoms are separated so much at the surface as greatly to diminish the elasticity, bringing the body into the state mentioned in *ph.* 44. and 46. the atoms being so far removed from each other, that the centers on the concave side are not brought by the bending sufficiently into the spherules of repulsion: and on the convex side there is great freedom of access for ethereal matter, and this lessens the attraction, which also is very much weakened on account of the greater distance.

PH. 49. A spring, when in use, frequently breaks suddenly, and this occurs chiefly in very cold weather.

Exp. If from a quick movement of the spring, any part of the convex surface should have its contiguous atoms so far separated, that the ethereal matter can rush between them on every part, the spring ought to break according to the foregoing explanations, and this is most likely to happen in cold weather, when the surface is most contracted by the diminished temperature.

Ph. 50. In raising the temperature of the steel through various degrees, it assumes successively the prismatic colours.

Exp. As the temperature is raised, the superficial atoms are more and more separated, and the inclosed ethereal atoms become more and more diffused as the heat increases; hence the surface acquires different conditions for the reflection of different sorts of ethereal atoms, and the different colours, doubtless, arises from the difference in the forces and spherules of the ethereal matter, which constitutes light, together with the greater or less velocity with which it is projected, and hence according to the state of the surface, we shall have all the different colours.

Ph. 51. Ductility and malleability, or the capacity of bodies to be drawn out into wire, flattened, or extended, by pressing, rolling, hammering, &c. belongs chiefly to the metals: in some, as gold, silver, &c. it is very great; while other metals, as tungsten, antimony, &c. are very brittle.

Exp. Bodies will be malleable and ductile, when their component atoms are capable of gliding over each other, without a separation by the accession of ethereal matter between them, and hence the parts will adhere together, while variously disposed, and distributed in the body. But when the body is such, that, on a slight displacement of its constituent atoms, the ethereal matter gains access between them, the body will easily break; on this account not only many of the metals, but several other bodies, are brittle: every one is aware of this property in glass, separate its parts but in a small degree, and immediately the newly exposed surfaces are covered with ethereal matter, and the glass is cracked.

Ph. 52. Malleability and transparency, are seldom found in the same body.

cylindrical vessel of glass which has been suddenly cooled; it is open at one end, and rounded at the bottom, which is made so thick as generally to bear a smart blow without breaking: but if a small pebble or piece of flint be let fall into it, it immediately cracks and the bottom falls to pieces.

Exp. In the sudden cooling the ethereal matter will be most expelled from the exterior surface, and will therefore lie nearer the interior side, because of the less rapid escape of caloric from within; hence the pebble or flint will easily cut the thin interior crust, and the fracture takes place, as explained above in respect of the glass tear.

PH. 57. If the glass tear be cut a small depth at the thick part of the tail, or if a hole be drilled in the thick part near the tail, it bursts in pieces as before.

Exp. In this case as above, a passage is opened for the ethereal matter, and from its rapid motion towards this part and through the opening, a disruption is produced, as when the tail was broken off.

PH. 58. When the glass drop is broken, a report or sound of considerable intensity is heard.

Exp. This also arises from the sudden extrication of ethereal matter; for sound is a common effect in all similar cases, arising from the displacement of a portion of air, which suddenly rushes together again; thus the report of a gun, thunder, and many other sounds, are produced. In this instance the sudden expansion of the inclosed caloric drives, with very great rapidity, the air and particles of glass apart on every side: hence the production of the sound establishes the *exp.* of *ph.* 55.

PH. 59. If the tail be broken in a vacuum, the fragments of the drop are dispersed with greater force, and broken into smaller parts, also a vivid light is observed.

Exp. There is in this case a less resistance to the rushing out, and escape of the ethereal atoms, and the phenomenon favours the foregoing explanations, and also proves that the ethereal matter, which produces the effect, is previously contained in the interior of the glass.

Ph. 60. If the regular working of a steam engine be interrupted, or stopped for a short time, so that the steam may accumulate in the boiler (although not beyond the degree, which in other cases comports with safety) and the boiler is put suddenly to work, it frequently bursts: this has been remarked in several instances.

Exp. During the time that the boiler is stopped, the density of the steam is increased, and consequently the caloric; and this last increases not only in the part of the boiler occupied by the steam, but in the water also, in which an abundant quantity of caloric will be condensed: now as soon as the engine is set to work, the steam, which first issues from the boiler, occasions a momentary diminution of pressure on the surface of the water, and consequently a body of steam, formed by the caloric which the water contains, immediately rushes forth, a vibratory motion necessarily ensues in the steam, which favours the exit of an additional quantity from the water, and it acts not only by its simple pressure, but also by the force of percussion in the vibrations, which greatly endangers the boiler, and sometimes bursts it in a moment.

Obs. This phenomenon is introduced here, to illustrate and establish some parts of the foregoing explanations respecting the glass tears.

Ph. 61. Very frequently the appearance of small air bubbles is seen in the glass tears, and if one of them be ground beginning from the thick end and proceeding towards the tail, when it is worn down to any large

bubble it bursts as usual, but when these are not in the way, the head may generally be ground off.

Exp. When the head is ground to one of these large bubbles a sufficient passage is made for the extrication of the ethereal matter, and the disruption takes place as before, but otherwise the grinding, which commences from the part where the ethereal matter is least condensed, and the cooled surface is the thickest, (see *exp.* of *ph.* 55). and where, consequently, it is less liable to burst, raises the temperature by means of the friction, and this excited heat serves as a further barrier to prevent the escape of ethereal matter that way, so long as the texture is uniform; hence generally the drop is not broken by this operation. Also the raised temperature anneals the glass, so that it remains firm in most cases after some part is worn off by grinding.

Ph. 62. If the drop be made red hot, and then slowly cooled, the tail may be broken any where, and the drop does not burst asunder.

Exp. By the red heat the ethereal matter is diffused, and by cooling slowly it is uniformly distributed, and a part dissipated: hence what remains is in a state of equilibrium, the surface now not confining an accumulated quantity of it, under a firm barrier, since it is retained on the exterior parts in nearly the same manner and degree as in the interior, and on this account no great disturbance takes place when the tail is broken.

Ph. 63. If the melted glass be dropped into liquid wax, or into oil, and the tail of the drop afterwards be broken, effects similar to those above mentioned will follow; only, that in this case, the fragments will be larger, and frequently a part of the tail may be broken as common glass.

Exp. The surface of the glass does not cool so rapidly

in these substances, as in water, because they are worse conductors of caloric, and hence, that such should be the difference in the effect is manifest.

PH. 64. The force of cohesion in solids is very frequently diminished and the volume augmented by increasing their temperature.

Exp. The caloric communicated to, and diffused through the bodies, while their temperature is raised, acts in conjunction with the ethereal matter already contained in them, and tends to separate, more or less, the constituent atoms or particles, and hence diminishes the cohesion, since, in most cases, by increasing the temperature the force of pressure between every two particles of the body is augmented, and the greater distance between the particles renders the volume greater.

PH. 65. The same solid expands more for the same increase of temperature, when the temperature is very high, than when it is at a low degree. In such bodies as are very infusible, the difference is small in all moderate temperatures, but increases rapidly in very high ones.

Exp. The same elevation of temperature produces the same increase of pressure between the atoms of the body, but in high temperatures the cohesion is much weakened, (*ph.* 64.); hence the same increased force of pressure will produce a greater effect in separating the atoms. This difference of cohesion will be very little in firm and infusible bodies, while the temperature is at any moderate degree: and hence in this case the dilatations will be very nearly equable.

PH. 66. Different solids do not expand to the same degree by equal additions of caloric.

Exp. This is a natural consequence, from the different forces, spherules, and arrangements of the atoms which compose the solid.

PH. 67. A body which has been heated from 32° to 212°, and again suffered to cool, recovers the same volume which it had at the commencement of the experiment.

Exp. For the atoms or particles have not been totally separated; hence when the caloric, or other ethereal matter which tended to separate them, and caused the expansion, is removed to the same degree, the same cohesive force will bring the particles to their first positions, and hence the former bulk is restored.

PH. 68. Different liquids do not expand equally from an equal increase of temperature. Thus alcohol expands much more than water, and water than mercury.

Exp. This will follow from the same cause as the different expansions of solids (*ph.* 65 and 66.) Thus let alcohol and water be at the same temperature, and let both be raised to the same degree higher; the force between the atoms of each to separate them is equally increased, but that increased force will have a greater effect on the alcohol, than on the water, partly because its cohesion is much less, and partly on account of the difference in its particles.

PH. 69. The same liquid expands more by an equal elevation of temperature, when its temperature is very high, than when it is nearly at the usual standard of the atmosphere.

Exp. In this liquids agree with solids, and for the same reason, see *ph.* 64 and 65, where the explanation is given.

PH. 70. Gases differ from solids and liquids in this, that they expand equally for equal elevations of temperature, both for different gases at the same, and the same gas at different temperatures.

Exp. That the gases expand equally was shewn (*ph.* 21. *sect.* iv.), the reason of the difference in the law of the ex-

pansion of gases in respect of liquids and solids, is, that in the latter, the expansion, the force causing it being given, depends in a great degree on the cohesion of the atoms, as well as on the pressure to which they are subjected: but in gases the cohesion is indefinitely small, so that the expansion is resisted by the pressure only.

PH. 71. The quantities of caloric requisite to raise the temperature of two bodies equally, is called their specific caloric; and the property of the bodies by which they require these particular quantities is called their capacities. According to the experiments of M. M. *Petit* and *Dulong* it seems probable, that the atoms of simple substances have the same specific caloric. Thus it is found that the specific caloric of lead is .0293, and that of nickel is .1035. Now the weight of an atom of lead is 12.95, and that of an atom of nickel is 3.69, according to these chemists, and the numbers nearly agree with those assigned by others. Now taking a given weight 1 of each metal, we have 1 : .0293 : : 12.95 : .3794 the specific caloric of an atom of lead, and 1 : .1035 : : 3.69 : .3819 the specific caloric of an atom of nickel. These results are so nearly the same, that the difference may be properly ascribed to unavoidable errors in the experiments. The same results nearly are found for several metals.

Exp. Whether or not the above conclusions truly correspond with real facts, is a point difficult to determine: however, it is indicated by the experiments, and our theory seems to favour this view: for while the bodies are under the same pressure, and at the same temperature, we may reasonably expect, that each atom of the different bodies will receive the same or nearly the same quantity of caloric, in order to be in an equal state for giving it out again, that is, in order that the temperatures be raised equally. At least we may expect this, if the bodies be of

a similar texture: yet even under these circumstances, some minute differences may be supposed to arise from the difference in the forces of the atoms.

Ph. 72. The greater the cohesion of a body is, the greater is the difficulty with which it enters into combination with another.

Exp. It is evident that when the atoms are placed together, they will with more difficulty be involved in each other's atmospherules, when the one is more closely and firmly attached to those of its own kind, than when it is connected with less force and closeness.

SECTION VI.

CHEMISTRY.

Phenomena relating to Affinity, and Chemical Composition.

When the force of attraction by which bodies, and their parts, are solicited towards each other, causes atoms, or particles of the same kind, to stick together more or less firmly, it is called cohesion, as already stated; but when atoms, or particles of different kinds, are united by attraction, the force receives the name of affinity, or chemical affinity.

Thus the particles of lime will unite with those of muriatic acid, and this union is said to be produced by the affinity of lime and muriatic acid: but oil will not unite with water, hence it is said, that there is no affinity between oil and water.

In some cases of affinity the original properties of the component parts are still perceptible, as when salt and water, or sugar and water unite, but in other cases these properties entirely disappear. Thus Epsom salt is composed of magnesia and sulphuric acid, or oil of vitriol, but the physical properties of these ingredients are not found in the salt.

As there is no apparent affinity between some bodies, and a very powerful affinity is evident between others, so,

between the vast variety of different bodies, innumerable degrees of affinity present themselves, and their actions are performed under various modifications.

Simple elective affinity is when two bodies, being united, and a third presented, that third body unites with one of the first, to the exclusion of the other of them: thus muriatic acid has more a powerful affinity for potassa than for lime, yet it will unite with either; suppose it is united to the lime, and if to a solution of the muriate of lime, a solution of potassa be added, the potassa will unite with the lime, to the exclusion of the muriatic acid.

Double elective affinity takes place when two compounds are decomposed, and two new combinations formed by the mutual actions of the bodies, as in the following example. Let saturated solutions of sulphate of zinc, and acetate of lead, be mixed, both will be decomposed, the zinc and acetic acid will unite and remain in solution, and the sulphuric acid and lead will also combine, and fall to the bottom of the vessel.

These and similar phenomena have been variously accounted for, and still much uncertainty embarrasses the subject; probably the present theory may lead to clearer views of what takes place in these operations.

For this purpose I proceed to present a multiplicity of facts, immediately connected with chemical affinity, and to apply the theory to their explanation.

In reading the explanations, let it be remembered, that particles have a kind of polarity, more or less marked, as stated in *sect.* ii. *prop.* 15. *cor.* 4, a circumstance, which greatly contributes to some particular combinations in preference to others.

Ph. 1. Many bodies of different kinds will readily unite, and form one body; but there are others, which do not easily combine; thus muriatic acid will unite with lime,

but water will not unite with carbonate of lime (chalk). Thousands of instances might be given, in which two different bodies enter into combination, and these are called cases of simple affinity.

Exp. This is explained in the same manner as *ph.* 5, 6, 7, 8, &c. *sect.* v. being of the same class. Now since the theory admits of great differences, not only in the forces of atoms, but also in the extent of their spherules; and, since the different atoms, and much more the different particles, which constitute bodies, will consequently collect very different quantities of ethereal matter to constitute their atmospherules, which will be accordingly of different extents and densities, and in the case of particles more accumulated on some sides than on others; we shall not be surprized that there is so great a variety of cases, and degrees of simple affinity, and also that some bodies will not, in common circumstances, unite at all; for, when the forces of the atoms or particles and the extent of their spherules are such, that they cannot bring the atmospherules of the one to enter into, and in some degree mix with the others, no union of the atoms or particles will take place, and we then say there is no affinity.

Thus suppose ABC, (*fig.* 28.) to represent a particle of water, which may be composed of two atoms of hydrogen and one of oxygen, surrounded with its atmospherule, and let *m* (*fig.* 14.) represent an atom of some other body. Now it is easy to conceive, that the absolute force of *m*, the extent of its spherule, and consequently the quantity and extent of its atmospherule, may be such, as that if placed sufficiently near, it shall attach itself to ABC with greater or less facility, or that it shall not combine with it at all; and in this respect every variety of degrees in combination may be supposed. Also different temperatures

will affect the combinations, since it alters the atmospherules.

PH. 2. It frequently happens, that when a body of one kind is presented, under suitable circumstances, to a compound body of another kind, it unites with one of the elements of the compound, to the exclusion of the other; thus if water be added to a compound of alcohol and camphor, the water unites with the alcohol, and the camphor is precipitated; again, if to muriate of magnesia in water, potassa be added, the potassa will unite with the muriatic acid, and remain in solution, while the magnesia is excluded, and falls to the bottom; in like manner, if to a solution of the nitrate of copper a piece of iron be presented, the nitric acid will unite with a portion of the iron, and the copper will be deposited; similar instances are innumerable, and this is called simple elective affinity, in which there is a decomposition of the compound, and a new combination formed.

Exp. Since, as in the foregoing phenomena, it may frequently happen, that when an atom or particle is placed near others of another kind, it will more or less easily unite with them, or not unite at all, so it is equally easy to see, from our theory, that in many cases, when an atom or particle unites with a compound body, the union may more easily take place, and be more intimately effected with the one, than with the other of the constituents, on account of the difference of the compounding atoms; and, the new atmospherules, instead of enveloping the whole, as a distinct particle, may only involve that with which it enters into the closest connection, the other is therefore necessarily excluded with a portion of ethereal matter forming its atmospherule. Thus there is a decomposition of the compound, one of its elements is liberated, and the other enters into a new combination with the body which

was presented. This will more clearly be seen from several particular cases, which will be explained. It may be observed that the separated atom will by *prop*. 14. *cor*. 9. *sect*. ii. be thrown off with a degree of repulsion.

PH. 3. When, as often occurs, the body presented to the compound as in the last phenomenon, does not unite with one of its elements, to the exclusion of the other, yet if the body presented be first combined with some other, and the compound thus formed be now presented to the other, under proper circumstances, an exchange of elements will frequently result. Thus, neither muriatic acid, nor lime, separately, will decompose sulphate of soda, but if muriate of lime be presented to sulphate of soda, dissolved in water, the sulphuric acid of the soda will unite with the lime, and the muriatic acid will unite with the soda; the sulphate of lime now formed will fall to the bottom, but the muriate of soda, which is likewise formed, will remain in solution. This is sometimes called double elective affinity. There are multitudes of instances of its occurrence as well as of those in *ph*. 1 and 2, and in many cases this double decomposition, and combination, does not take place. Also temperature has considerable influence in these changes.

Exp. That a substance, as muriatic acid, or lime, may not be capable of decomposing a compound, as sulphate of soda, appears from the last explanation; but still muriatic acid and lime may unite with each other, and the particles of this compound, *viz*. muriate of lime, may, from the change which has occurred in its conformation, composition, and atmospherule, be capable of entering into union with a particle of the sulphate of soda, according to what was noticed in the two preceding explanations, and the union may be such, that the lime and sulphuric acid shall unite to the exclusion of the soda and

muriatic acid, which will unite and be separated from the mass, as pointed out before.

For at the instant when the muriate of lime and the sulphate of soda enter into combination, it will depend on the forces, spherules, and atmospherules of the four substances, *viz.* soda, lime, sulphuric acid, and muriatic acid, whether they shall be enveloped in one atmospherule, so as to form one particle, or two of them, from their close connection shall become one particle to the exclusion of the others. It is manifest that the theory favours a great variety in these decompositions and combinations, which evidently will be greatly modified by the temperature of the solvent, or of the bodies.

PH. 4. One of the circumstances requisite for the combination of atoms, or particles, is, that they should be placed in apparent contact, that is, at an insensible distance.

Exp. For first, it is evident from the theory, that the force exerted between the particles of bodies at a sensible distance must be so very minute, that it cannot be supposed capable of overcoming small obstacles, which may be present; such as adhesion to other near particles, effects, of caloric, &c. and secondly the atmospherules, surrounding the particles, not only oppose the union, but produce a repulsive force tending to keep them asunder, and hence they cannot unite, but when at insensible distances, and under such circumstances, that they can penetrate each other's atmospherules, so as to be involved in one atmospherule, the two atoms or particles in that case will constitute a single particle, and this exhibits the true effect of marked chemical composition, in which we may expect that the nature of the compound will greatly differ from that of either of its constituents.

Ph. 5. Some bodies unite in all proportions; as sulphuric acid and water, or alcohol and water.

Exp. In this case one particle of one body simply coheres to, or unites with one or more of the other, and the particles which remain in excess, of the one, will be uniformly diffused among these combined or adhering particles, after the manner in which the gases mix together uniformly, as explained *ph.* 22. *sect.* iv.; in such cases therefore the substances will combine in all proportions.

Ph. 6. Some bodies combine in all proportions within certain limits, beyond which there is no farther combination.

Thus a given quantity of water will dissolve any quantity of salt to a certain limit, beyond which if more salt be added it falls to the bottom: for instance, 100 grains of water will dissolve any quantity of common salt not exceeding 40 grains, if more than this be put into the water, the excess will remain in its solid state, not being dissolved.

Exp. In this case, as in the last, one particle of one body coheres with one or more of the other; and if one body, for example the water, be in excess, its uncombined particles are diffused among the compounded ones, but if the other *viz.* the salt, be in excess, it falls to the bottom, either because its specific gravity is too great for it to be suspended or to mix, as in *ph.* 5, or as the different gases, *ph.* 22. *sect.* iv. or from some other circumstance in its constitution preventing its uniform diffusion.

Ph. 7. When bodies combine in all proportions, or in all proportions within certain limits, as in the two last cases, the combinations are easily destroyed: thus alcohol is separated from water, and water from sulphuric acid, or from salt, by heat alone.

Exp. This indicates a weak combination or coherence, and confirms the foregoing explanations, for, under these circumstances, it is easily perceived, that when an increased quantity of caloric is presented, the cohering particles will become distinct, each becoming, by the acquisition of ethereal matter, enveloped in its own atmospherule, and that which is most easily converted into vapour, will consequently be expelled in the state of gas or vapour.

Ph. 8. Such combinations as noticed in the last phenomenon, retain sensibly the properties of the component ingredients.

Exp. This also will follow from the want of intimate connection, the two particles not being completely but rather indistinctly involved in the same atmospherules, or at least are easily separated, (*ph.* 7) and exhibit the natural properties; and therefore this, and the three foregoing explanations corroborate each other.

Ph. 9. Sometimes bodies unite in one proportion only; thus one part by weight of hydrogen, will unite with thirty-six of chlorine, forming muriatic acid: and these substances are not known to combine in any other ratio.

Exp. Here it may be observed, that when the compound is formed, as in *ph.* 5 and 6, that is, by one atom, or a fixed number of atoms of the one, uniting with one, or with a fixed number of the other, (most probably one with one) they are enveloped completely and intimately in one atmospherule, in consequence of this the union is so close, and distinct, that the compound is separated from an excess of either of its component parts, or, at least, is very easily discerned as a different substance, and hence they combine in that one proportion only: in this instance equal volumes of the two gases unite, and if there be an excess of either, it remains uncombined, and in a state of mixture.

PH. 10. Again, various bodies unite in only a few definite proportions, the number of these seldom exceeds five, and in this case, one of the combinations being formed, as in the last phenomenon, the new compound under proper circumstances may be made to combine in like manner, with the same fixed quantity of one of its elements, as that with which it before combined, and this forms a second proportion; this again sometimes may be put into such a condition, as to unite once more with a like portion of one of the original elements; in this way there may be in some instances, a fourth, a fifth, or even a sixth compound of the same elements obtained, yet the number seldom amounts to six or even to five. Thus two compounds of carbonic acid and potassa may be obtained, in one of which is found just twice as much carbonic acid as in the other; the weight of potassa being given.

Exp. The explanation of this, as far as it regards the combinations, is the same as that of the preceding; for a single combination being obtained, the new body may be put into circumstances, under which, with one of the elements, another single compound may be formed; and in some cases this may occur a third time, &c.—As it regards the proportion, it is evident, that the new compound, first formed, contains the same number of particles which each of its elements contained before combination, and that consequently, it will again unite with the same number; as will be more clearly seen in what follows.

PH. 11. When bodies unite in one or a few definite proportions only, the new compounds differ exceedingly in their properties from either of the elements which produced the combination.

Thus oxygen and sulphur form sulphuric acid, which is very unlike either of them.

Exp. When two atoms or particles of different kinds unite closely, and so as to be completely enveloped in the same atmospherule, it is to be expected, that the separate elements, and the new particle, will differently affect adjacent bodies, and be differently affected by them, that is they will have very different properties; and this strengthens the explanations of the two preceding phenomena.

PH. 12. When bodies unite in different definite proportions, the smallest proportion of one body being taken, the other proportions are exactly twice, thrice, &c. that quantity in almost all cases, but sometimes one and one half that smallest quantity enters into one of the combinations, and possibly there may be other proportions.

Thus carbonic acid contains just twice as much oxygen as carbonic oxide, to the same weight of carbon; and sulphuric acid contains just three times as much oxygen as the hyposulphurous acid to the same quantity of sulphur; also the red oxide of iron contains exactly one and a half times as much oxygen as there is in the black oxide.

Exp. Conceive in the composition, for instance, of carbonic oxide, that one atom of oxygen combines with one or more of carbon, it is evident that there will be formed as many particles of carbonic oxide, as there are atoms of oxygen employed; now let more oxygen be presented to the oxide, under proper circumstances, a new combination can be effected, and the quantity of oxygen again entering into combination must just equal the former quantity; either, if each atom of the oxide combine with one of oxygen; or, (on the supposition that the oxide contains two atoms of carbon in each particle) one atom of oxygen uniting with the oxide separates and takes to itself one atom of carbon, leaving a like particle consisting of one

atom carbon and one oxygen: and either of these is consistent with the theory and with the foregoing explanations, as well as with the facts themselves: and similarly the other cases may be shewn to agree with the theory and to exhibit its probable results: thus in respect of iron, its black oxide being formed, two of its atoms uniting with one of oxygen will form the red oxide; the theory itself will lead us to the conclusion that in some cases one atom will combine with two atoms, or particles, more readily than one with one.

Ph. 13. When bodies combine, the specific gravity is most frequently, but not always, greater than the mean of the bodies, of which it is composed.

Exp. This we might expect generally to arise from the union of particles, their natural attractions rendering them more compact, but sometimes the atoms combining, and the circumstances of the case may be such as to produce a different effect.

Ph. 14. In chemical union the temperature is generally altered.

Exp. For on the combination of atoms, or particles, the newly formed particle will be in a different state in respect to the atmospherules, in many cases requiring a less quantity of caloric than that contained in both of the two combining particles, and sometimes, although seldom, a greater quantity; the temperature is increased in the first case, and diminished in the second.

Ph. 15. Combination often produces a change of form; thus solids may become fluids, and fluids, solids.

Exp. This may easily occur according to the theory, as will appear from a consideration of the foregoing phenomena; and evidently the resulting form will depend on the atoms which combine, and the ethereal matter which they contain, and retain after union.

Pr. III. A change of colour is often produced in bodies by chemical union.

Exp. Since colour depends on the texture and nature of the bodies which reflect light, causing them to reflect certain sorts more copiously, such changes ought to take place, when bodies unite chemically, for the nature and texture of the body is generally quite changed.

Pr. IV. If there be several bodies A, B, C, D, &c. of one class, whose quantities are a, b, c, &c. respectively; and also several A', B', C', D', &c. of another class, whose quantities are a', b', c', &c. those of the one class being capable of combining with those of the other in definite proportions: then if a, b, c, d, &c. of the first class, are just the quantities which will combine with a' of the second, and b', c', &c. the quantities of the second which will combine with the quantity a; then any one of the first, will exactly saturate, or neutralise any one of the second.

Thus let the following columns represent the two classes and their quantities.

Phosphoric acid	$28 = a$	Magnesia	$20 = a'$
Muriatic acid	$37 = b$	Lime	$28 = b'$
Sulphuric acid	$40 = c$	Soda	$32 = c'$
Nitric acid	$54 = d$	Potassa	$48 = d'$
		Barytes	$78 = e'$

Then the weight represented by the number annexed to any one of either class will combine with that of any one of the other class.

Thus 37 of muriatic acid will saturate 28 of lime, or 32 of soda, &c.

Exp. Since each of the first class will combine with $a' = 20$, of the second, there are the same number of combining particles in each of those weights as there are in a' according to the foregoing explanations; and since

atom carbon and one oxygen; and either of these is consistent with the theory, and with the foregoing explanations, as well as with the facts themselves; and similarly the other cases may be shewn to agree with the theory and to exhibit its probable results; thus in respect of iron, its black oxide being formed, two of its atoms uniting with one of oxygen will form the red oxide; the theory itself will lead us to the conclusion that in some cases one atom will combine with two atoms, or particles, more readily than one with one.

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Exp. This may easily occur according to the theory, as will appear from a consideration of the foregoing phenomena; and evidently the resulting form will depend on the atoms which combine, and the ethereal matter which they contain, and retain after union.

Ph. 16. A change of colour is often produced in bodies by chemical union.

Exp. Since colour depends on the texture and nature of the bodies which reflect light, causing them to reflect certain sorts most copiously, such changes ought to take place, when bodies unite chemically, for the nature and texture of the body is generally quite changed.

Ph. 17. If there be several bodies A, B, C, D, &c. of one class, whose quantities are a, b, c, &c. respectively and also several A′, B′, C′, D′, &c. of another class, whose quantities are a', b', c', &c. those of the one class being capable of combining with those of the other in definite proportions; then if a, b, c, d, &c. of the first class, are just the quantities which will combine with a' of the second, and b', c', &c. the quantities of the second which will combine with the quantity a; then any one of the first, will exactly saturate, or neutralize any one of the second.

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Then the weight represented by the number annexed to any one of either class will combine with that of any one of the other class.

Thus 37 of muriatic acid will saturate 28 of lime, or 32 of soda, &c.

Exp. Since each of the first class will combine with $a' = 20$, of the second, there are the same number of combining particles in each of those weights as there are in a' according to the foregoing explanations; and since

each of the second class will combine with $a = 3$ of the first; each of these also contains the same number of combining particles, with each other, and with those of the first class, and hence any two are in the proper proportions to combine, so as to form a distinct compound agreeably to the preceding phenomena and explanations.

Ph. 18. When two neutral salts decompose each other, as muriate of lime, and sulphate of soda, given as an example in *ph.* 3, the new salts are also neutral.

Exp. This follows from *ph.* 17. above, of which it is but a particular case.

Ph. 19. When a body decomposes a compound, to which it is presented, as in *ph.* 3, and exactly the proper quantity for the complete decomposition is employed, it very frequently occurs, that only a partial decomposition takes place: thus sulphuric acid, presented to nitrate of potassa, unites with the potassa to the exclusion of the nitric acid, which is set free; now 40 grains of sulphuric acid will just suffice to saturate 48 grains of potassa, the quantity contained in 102 grains of the nitrate; yet the 40 grains of sulphuric acid will not decompose the 102 grains of nitrate of potassa.

Exp. At first the decomposition may be supposed to proceed with facility, but as the nitric acid is set free, it may still adhere to the particles of the newly formed sulphate, or to the remaining sulphuric acid, or to the water of the solution, or even to two or more of these: and this will evidently more or less present a barrier to the progress of decomposition.—Hence a larger quantity of sulphuric acid is requisite to separate all the potassa.

Ph. 20. Although a body will decompose another by uniting with one of its elements, yet sometimes the liberated element will, in its turn partially decompose the new body: thus nitric acid will separate potassa from

sulphate of potassa, and on the contrary, as in the preceding phenomenon, sulphuric acid will decompose the nitrate of potassa.

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Ph. 22. The like will happen commonly when the new compound, or even the body liberated, assumes the elastic form, and consequently rises, as a gas or vapour.

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Exp. At first the decomposition may be supposed to proceed with facility, but as the nitric acid is set free, it may still adhere to the particles of the newly formed sulphate, or to the remaining sulphuric acid, or to the water of the solution, or even to two or more of these: and this will evidently more or less present a barrier to the progress of decomposition.—Hence a larger quantity of sulphuric acid is requisite to separate all the potassa.

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ing, and at other times opposing the union of bodies, according to circumstances.

Exp. That such should be the effects of these agents will appear from what has been advanced, and will be seen more clearly from a great variety of instances which will be given as we proceed.

Ph. 24. The application of caloric alone, in many cases is sufficient, not only to prevent chemical union, but to destroy combinations already formed; thus carbonate of lime, or chalk, which is composed of lime and carbonic acid, will be decomposed by the application of a strong heat, the carbonic acid escapes in the form of gas, and the pure lime remains.

Exp. The particles of lime and of carbonic acid are such, and are so united, that the caloric increasing and pressing on their spherules, separates the particles, those of the carbonic acid acquiring ethereal matter sufficient to render the substance gaseous.

Ph. 25. Mechanical pressure has considerable influence on chemical affinity: thus if the chalk, in the above example, be placed under strong pressure, an intense heat will not expel the carbonic acid.

Exp. The pressure on every side tends to keep the particles of the compound together, so that the caloric is diffused in the common atmospherules of the compound particles and cannot come between, so as to separate them, which it would do according to the preceding explanation, if the pressure were removed. This fact confirms the explanation of the foregoing.

Of the Combinations of Gases.

PH. 26. Some gases will combine when simply mixed together: thus oxygen will unite with nitrous gas, and ammonia with muriatic acid gas.

Exp. When the gases are mixed together, their atoms attract each other, in all cases, on which account, and from the difference of their spherules and atmospherules, there will be a tendency to uniform mixture (*ph.* 22. *sect.* iv.); now these differences, together with the different forces of the atoms, may be such, that an immediate union, instead of a mere mixture shall take place, so that an atom or particle of each of the two gases shall be involved in one atmospherule, forming a new body, (see *prop.* 25. *sect.* ii.) and this is still more probable, if one or both of the gases be already a compound. Pure oxygen and nitrogen, if put into the same vessel, will simply mix together, but a composition of these two substances may be obtained, which is called nitrous gas, or deutoxide of nitrogen, and which is found to consist of one volume of oxygen united to one volume of nitrogen, making two volumes of the compound gas; now although the nitrogen will not, on mere mixture, combine or unite with oxygen, yet this compound readily absorbs the oxygen into its atmospherule, and forms with it a particle of nitrous acid, and this evidently is agreeable to our principles.

PH. 27. When gases combine, the new body is, in some cases, a gas, in others it is a liquid or a solid.

Exp. This will follow from the principles already developed; when bodies unite chemically, the form of the resulting compound depends on the substances, which enter into the combination.

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Exp. That such should be the effects of these agents will appear from what has been advanced, and will be seen more clearly from a great variety of instances which will be given as we proceed.

Ph. 24. The application of caloric alone, in many cases is sufficient, not only to prevent chemical union, but to destroy combinations already formed; thus carbonate of lime, or chalk, which is composed of lime and carbonic acid, will be decomposed by the application of a strong heat, the carbonic acid escapes in the form of gas, and the pure lime remains.

Exp. The particles of lime and of carbonic acid are such, and are so united, that the caloric increasing and pressing on their spherules, separates the particles, those of the carbonic acid acquiring ethereal matter sufficient to render the substance gaseous.

Ph. 25. Mechanical pressure has considerable influence on chemical affinity: thus if the chalk, in the above example, be placed under strong pressure, an intense heat will not expel the carbonic acid.

Exp. The pressure on every side tends to keep the particles of the compound together, so that the caloric is diffused in the common atmospherules of the compound particles and cannot come between, so as to separate them, which it would do according to the preceding explanation, if the pressure were removed. This fact confirms the explanation of the foregoing.

Of the Combinations of Gases.

Ph. 26. Some gases will combine when simply mixed together: thus oxygen will unite with nitrous gas, and ammonia with muriatic acid gas.

Exp. When the gases are mixed together, their atoms attract each other, in all cases, on which account, and from the difference of their spherules and atmospherules, there will be a tendency to uniform mixture (*ph.* 22. *sect.* iv.); now these differences, together with the different forces of the atoms, may be such, that an immediate union, instead of a mere mixture shall take place, so that an atom or particle of each of the two gases shall be involved in one atmospherule, forming a new body, (see *prop.* 25. *sect.* ii.) and this is still more probable, if one or both of the gases be already a compound. Pure oxygen and nitrogen, if put into the same vessel, will simply mix together, but a composition of these two substances may be obtained, which is called nitrous gas, or deutoxide of nitrogen, and which is found to consist of one volume of oxygen united to one volume of nitrogen, making two volumes of the compound gas; now although the nitrogen will not, on mere mixture, combine or unite with oxygen, yet this compound readily absorbs the oxygen into its atmospherule, and forms with it a particle of nitrous acid, and this evidently is agreeable to our principles.

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Thus nitrous gas and oxygen produce nitrous acid gas, but ammonia and muriatic acid yield the solid muriate of ammonia : the combining atoms may evidently be such as to favour these forms.

PH. 28. Some gases, which will not unite under common circumstances, may be made to combine under certain conditions, as by the agency of light, caloric, or electricity, &c.

Exp. The theory evidently accords with these facts; because these substances greatly affect the atmospherules, which will be more fully explained and illustrated in the following particular cases.

Obs. If oxygen and hydrogen be introduced in any proportions into the same vessel, these gases will constitute a simple uniform mixture, (*ph.* 22. *sect.* iv.) but under various circumstances, as by the electric spark, increased temperature, &c. they combine and present several interesting phenomena.

PH. 29. If the mixture above noticed contain two volumes of hydrogen, and one of oxygen, and an electric spark be passed through them, they combine with detonation, the developement of light and heat, and the disappearance of the gases, which now are converted into water.

Exp. The exceedingly rapid passage, and the repulsive force of the body of electric fluid, constituting the electric spark, (see *sect.* vii.) presses and impels the atoms of hydrogen and oxygen, in the immediate vicinity of its path, into each other's atmospherules, and the combination being effected, the sudden discharge of the major part of the ethereal matter of the combined atoms, at once produces a like effect on every side of it, which extricating a still greater body of ethereal matter, the total effect of combination is suddenly completed. The light and

heat which is extricated is accounted for in the disengagement of the ethereal matter.

The report arises in the usual way, by the percussion of the air, which rushes into the vacuum made by the condensation of the gases, which now occupy but a very small space in the form of water.

From the 22 and 23 *propositions* with the 15 and 16th, *section* ii., and *phenomena* 25, 26, 27, and 28, *section* iv., together with the fact, that two volumes of hydrogen combine exactly with one of oxygen, it appears, that two atoms of hydrogen combine with one of oxygen to form a particle of water, the above references will shew that this combination is more likely to be formed, and when formed, will be more permanent than the union of one atom of each sort.

Ph. 30. If the mixture contain a larger proportion of either of the ingredients than that stated above, the part, of the one, or the other, which is in excess, remains in its gaseous form.

Exp. The union of two atoms of hydrogen with one of oxygen, proceeds as above, till every one of oxygen, or every two of hydrogen is exhausted or nearly so, and after this, the process is necessarily stopped, and the superfluous gas remains.

Ph. 31. The same effect on the mixture of hydrogen and oxygen is produced by the application of flame, or of a solid heated to bright redness, or to any higher temperature.

Exp. The effect being produced by the hot body at the point of application, it will be propagated with rapidity as above explained.

Ph. 32. The mixture in the proportions stated (*ph.* 29.) explodes when a sudden and violent pressure is applied in a proper vessel, as in a syringe.

Exp. This follows similarly in consequence of the heat developed by the sudden and great pressure, aided by the compression produced.

PH. 33. If recently prepared spongy platina be placed in the mixture, (*ph.* 29.) the combination is effected by it, and this is performed in a short time, if a jet of hydrogen be thrown on the metal, which then quickly becomes red hot, and the mixture explodes.

Exp. We have here only to explain the first effect, and the elevation of temperature of the metal, the rest being as in *ph.* 29, and the two following. And first, it is necessary that the metal be in a finely divided state, now such is the nature of platina, that oxygen does not easily unite with it, and much less hydrogen, but they are attracted by it, and hence will be brought very near to each other at the fine metallic points which readily receive or give out ethereal matter, (see *prop.* 17, and its *cors.*) hence the atoms of oxygen and hydrogen in contact with these points of the finely divided platina will be in a state to combine with facility, and the atmospherules discharged by the combination will elevate the temperature of the metal, which is a bad conductor of heat, this effect will be more rapidly produced when the jet of hydrogen is thrown on the metal, both from the closer contact occasioned by the motion, and the quick succession of fresh atoms, and this speedily produces heat sufficient to cause the explosion. That other metals do not produce this effect may arise, partly from the relations of the atoms composing them, and those which are acted on; and partly perhaps because other metals cannot be brought into a state of equal fineness at the extremities, and also, partly because platina is a slow conductor of caloric.

PH. 34. When the proportion of hydrogen and oxygen differs more and more from that of *ph.* 29, the explosions

become continually less violent, till they are scarcely perceptible, and at length cease.

Exp. This evidently arises from the greater space into which the combining atoms are dispersed, and the intervention of the part or portion of gas which exceeds, since the whole (*ph.* 22. *sect.* iv.) will be uniformly diffused.

Ph. 35. When the mixture consists of about 17 volumes or more of oxygen, to one of hydrogen, or about 26 volumes or more of hydrogen to one of oxygen the explosion ceases to take place; as it does also when 12 volumes or more of common air are added to one volume of the mixture of *ph.* 29. Yet still a silent and gradual combination may be produced by the action of the electric spark, heat, or spongy platina.

Exp. Here the state of dilution is such, that the combining atoms are greatly dispersed, and the electric spark can only cause the combination of those atoms which are found in the line of its action, and hence a continued succession of sparks is necessary to produce a sensible effect; also the action of heat rarifies the atmospherules at the place of its application, and dissipates a portion of ethereal matter, which by passing off to the surrounding atoms, causes a motion there, and an action, which brings the atoms, whose atmospherules are most rarefied, into union under the great pressure which is produced; and this being effected, the tendency to uniform mixture (*ph.* 22. *sect.* iv.) brings other atoms to the place of action; and also in a similar manner, the process goes on by the agency of divided platina which will act when the proportion of oxygen is very large.

Ph. 36. The mixture *ph.* 28. will begin to unite slowly by the bare increase of temperature, from the boiling point of mercury to the heat at which glass begins to appear luminous in the dark.—Sir *H. Davy.*

Exp. This is explained as that part of the foregoing which relates to the application of heat.

Ph. 37. When the temperature of the mixture is raised, as in the last case, an explosion will be produced by a body less hot than would be required at a lower temperature of the mixture.

Exp. For this less addition of heat, combined with the increased caloric of the mixture, will be sufficient for the sudden combination requisite to produce the explosion.

Ph. 38. When the mixture is rarefied eighteen times, by diminished pressure, the electric spark does not produce an explosion, but causes it to combine silently.

Exp. Fewer atoms will combine in the path of the electric spark, than when the mixture is of the common density, both because of the greater distance between them and the easier progress of the spark (see *sect.* vii.), and also the diminished quantity of ethereal matter liberated, will have less effect, because of the less pressure and density of the mixture, hence there will be only a slow combination in the paths of the successive sparks.

Ph. 39. When the gases are in contact, but not mixed, the hydrogen may be inflamed at the common surface, and will burn with a soft lambent flame, giving out light and heat; as when a vessel of hydrogen is held with its mouth downward, and lighted at the surface, in contact with the air.

Exp. The gases will unite at the common surface as before, but being in contact only at that surface, and not mixed, it is evident that the rapid combination cannot be propagated either way: and the flame, with the light and heat, arises from the rapid union of the atoms of hydrogen and oxygen, which liberates and disperses the ethereal atmospherules, and continues the process, the contact being preserved by the pressure of the air.

Sch. Water may be again resolved into its elements by the agency of electricity, as will be explained in the section on *Galvanism.*

Besides water there is another compound of oxygen and hydrogen, called deutoxide, or more properly, peroxide of hydrogen, it contains twice as much oxygen as enters into the composition of water, the quantity of hydrogen being the same. Some care is required in its preparation, the complete process is described by M. *Thenard,* who discovered it in the year 1818.—See Dr. *Henry*'s Chemistry, vol. i. p. 263 and 264. If water consist of one atom of hydrogen united with one of oxygen, then the peroxide consists of one atom of hydrogen united to two of oxygen; but if water be constituted of two atoms of hydrogen and one of oxygen, then the peroxide contains one atom of each. The first of these views is that which is generally received by chemists, but I have not met with any solid reason for its adoption, the principles employed in our explanations agree altogether with the latter notion. See *sch. ph.* 25, *sect.* iv, and the following phenomena relating to this compound.

PH. 40. The peroxide of hydrogen is rapidly decomposed at a temperature of 58° Fahr. or upwards, and oxygen gas is liberated in great abundance.

Exp. According to the *sch.* to *ph.* 25, *sect.* iv, a particle of the peroxide will be represented by AB, (*fig.* 25), and it is there shewn, (and it also appears from *prop.* 16. and its *cors. sect.* ii.) that this combination is easily destroyed by an accession of ethereal matter; and hence the combination cannot exist in elevated temperatures. Now when the atom of oxygen A is separated, the two atoms A and B tend to recede by the ethereal matter coming between them, (*prop.* 14. *cor.* 9), and hence the atom of hydrogen B is pressed towards the contiguous particle of

the peroxide with which it easily enters into combination (as shewn in the same *scholium*) and forms a particle of water. Hence the liberated atom of oxygen escapes, which accounts for the extrication of the oxygen gas.

Ph. 41. The peroxide of hydrogen cannot be formed by operating on a simple mixture of oxygen and hydrogen gases, or by presenting oxygen to water, without the intervention of other substances.

Exp. Since it appears, from what has been advanced in several of the preceding phenomena, that the combination of two atoms of hydrogen with one of oxygen (*fig.* 25, 28, and 29,) is more easily effected, and more strongly supported, than that of one with one of each; it follows that in every way in which they can be simply combined, water will be formed, and sustained in its state, in preference to the peroxide.

Ph. 42. If with a little water, a proper quantity of concentrated muriatic acid be mixed, and to the mixture, surrounded by ice, small portions of deutoxide of barium in powder be successively added, stirring with a glass rod, the deutoxide is decomposed without effervescence, and protoxide of barium, or baryta remains in solution, this is precipitated by sulphuric acid, and another portion of the deutoxide of barium is presented, the process is repeated with proper precautions a sufficient number of times, and then the muriatic acid is removed by sulphate of silver; the residue is placed with a vessel of strong sulphuric acid under an exhausted receiver, to absorb the water which remains, and thus peroxide of hydrogen is formed, of which the specific gravity is 1.452.

Exp. In this process the muriatic acid unites with the deutoxide of barium to the exclusion of half of its oxygen, that is an atom of oxygen is separated from each particle. Conceive two particles of these substances entering into

union, while in contact with an atom ABC of water (*fig.* 28,) where B and C represent hydrogen, and A, oxygen, the atom of oxygen which is excluded from the barium will be pressed against the particle of water, by the attraction between the muriatic acid, and the hydrogen of the water; and, because of its great force in comparison of hydrogen, it will be strongly attracted towards A; suppose from the point *m*, this will bring the center of the excluded atom of oxygen, to the surface of the spherule of one of the atoms of the hydrogen in the particle of water, which will therefore reduce the particle (*fig.* 28.) to the form as seen in *fig.* 42, and the atmospherules at *x*, separating these, will evidently produce two particles, such as represented in *fig.* 25, being the peroxide of hydrogen. The repetitions in the process are useful to increase the quantity of this substance; the necessity of surrounding the vessel with ice will appear from the preceding phenomenon; for the combination cannot be maintained, much less formed in moderately high temperatures, the increased specific gravity should be expected, from the greater force and less spherule of the oxygen in comparison with hydrogen.

Ph. 43. When the peroxide of hydrogen is mixed with water, it is not quite so easily decomposed.

Exp. The adherence between its particles and those of the water will afford a sufficient reason.

Ph. 44. Strong acids added to the peroxide of hydrogen, render it less liable to decomposition.

Exp. This will follow by allowing that the acid adheres to the hydrogen more readily than to the oxygen, or to both in union, for in this case the particles of the peroxide are preserved entire and distinct.

Ph. 45. A piece of almost any metal will slowly decompose the peroxide of hydrogen.

Exp. Let AB (*fig.* 43) be the metal to which the oxygen *m* adheres more readily than the hydrogen D, hence, since metals are good conductors of ethereal matter, and readily admit its diffusion, (see *ph.* 6. *sect.* vii.) the atmospherule of D*m* will extend towards the side next to AB (*prop.* 26. *sect.* ii.) and hence the oxygen *n*, of another particle of the peroxide of hydrogen C*n*, will readily enter the surface of the spherule of D; the ethereal matter consequently liberated between C and D at *n*, will now act to favour the separation of *m*, and C *n* D will in consequence become a particle of water.

Pн. 46. If the metal be in a finely divided state, the decomposition will proceed with much greater rapidity.

Exp. For (*prop.* 17, and *cors.*) it follows that the points, angles, and edges of the metal, will transmit the ethereal matter much more than the flat surfaces, and thus they will promote the decomposition.

Pн. 47. In the two last cases, the metals which have a powerful affinity for oxygen, as zinc, &c. are oxidized, but others as gold, silver, &c. remain in their metallic state.

Exp. When the atom *m* of oxygen (*fig.* 43,) is liberated, as in *ph.* 45, it will combine with the metal or not, according to its force, the extent of its spherules, and the ethereal matter connected with them, that is, according to the affinity of the two substances: and this accounts for the difference in regard to the oxidation of the metals.

Pн. 48. Many of the metallic oxides, decompose the peroxide of hydrogen at common temperatures.

Exp. This is explained as the 45th and 46th preceding.

Pн. 49. The protoxides of several metals used as in *ph.* 48, for example, those of iron, tin, &c. are converted into peroxides.

Exp. The oxygen liberated, as in *ph.* 45, unites with

the protoxide by the attraction between them, and thus produces the change.

PH. 50. Some of the oxides, employed as above, do not pass into a higher degree of oxidation.

Exp. This must be the consequence, when the circumstances are such that the liberated oxygen does not combine with the oxide; and hence it will escape in the form of gas.

PH. 51. The metallic oxides, which are decomposed by a red heat, such as gold, silver, &c. are reduced to the metallic state, when employed as in *ph.* 48, and oxygen gas rises with effervescence.

Exp. Suppose an atom of oxygen united with the metal AB (*fig.* 43.) in contact with the atom of oxygen *m*, the force between them may be such as to loosen and separate the atom of oxygen from the metal, when its affinity for the metal is small, hence ethereal matter getting between the metal and the oxygen it is liberated, as well as the atom *m*, and both rise together in the form of gas, producing its more rapid evolution, and consequently a great effervescence, leaving the metal in a pure state.

PH. 52. It was discovered by M. *Gay-Lussac,* and confirmed by others, that gases combine in a simple ratio of their volumes; that is one volume with one, or one with two, or one with three, &c.

Exp. It appears from *props.* 22 and 23 and their *cors. sect.* ii. that although the forces and spherules of atoms differ considerably; yet they will in most cases contain the same number of atoms, or particles, in the same volumes; also from *ph.* 12. of this *sect.* it is seen, that the atoms or particles combine in definite proportions, it consequently follows that the combining volumes will also be generally in definite proportions.

PH. 53. When two gases unite and the product is a gas

or vapour, it is found, that frequently the volume of the original gases, is to that of the resulting gas, in a very simple ratio, sometimes the volume remains unchanged, and in other cases there is a contraction to two thirds, one half, one third, &c. and there are cases also in which the ratios are less simple. Two volumes of muriatic acid gas are composed of one volume of chlorine, and one volume of hydrogen; and two volumes of steam are composed of one volume of oxygen and two of hydrogen.

Exp. The resulting volume of the combination will depend on the position and connection of the tenacious atoms combined; thus if B (*fig.* 23.) represent an atom of hydrogen and A one of chlorine, combined as in the figure, the volume will not be altered, because there are the same central supporters of the atmospherules, and AB will represent a particle of muriatic acid gas; again, if A (*fig.* 29.) represent an atom of oxygen, and B, C, atoms of hydrogen, then if combined as in the figure CAB will represent a particle of steam, consisting of two volumes, one volume being condensed by the intermediate position of the center of the atom A. These examples serve to shew that the theory agrees with this remarkable law; some other instances will be noticed as we proceed.

PH. 54. If equal volumes of chlorine and hydrogen, which contain by weight 36 chlorine and one hydrogen, be mixed in a dry glass vessel, they will continue in a state of mixture for a long time, if the light be carefully excluded; but if exposed to common day light, and not to the direct rays of the sun, they will gradually unite, so that the combination will be effected in about fourteen hours, more or less according to the degree of light. The compound formed is muriatic acid gas, and is equal in volume to the measure of the two gases employed.

Exp. From *prop.* 23. *cor.* 4, *sect.* ii, it appears that

there is an equal number of atoms of each kind, hence they combine atom to atom, also from the great weight of chlorine, and its tendency to a gaseous form, we may collect, from *cor.* 6, of the same *prop.* that it has an extended spherule, probably as large as that of hydrogen; this supposed, let B (*fig.* 20.) represent an atom of hydrogen, whose force is 1, and A an atom of chlorine, its force being equal to 36; then in a gaseous mixture of these, it is evident, that the ethereal matter of the feeble atom B, will be pressed towards the side F, but, if there be no increase of ethereal matter, the hydrogen and chlorine may continue in a state of mixture. Again when there is a moderate accession of ethereal matter (see *prop.* 15, and 16, with their *cors.*) the combination *fig.* 23. may take place; and if this accession be made by the gentle action of common day light, the combination may be expected to proceed gradually.

Ph. 55. When a mixture of hydrogen and chlorine, as in the last phenomenon, is exposed to the action of the electric spark, a red hot body, flame, or the direct rays of the sun, a sudden combination is effected with explosion, and the emission of light and heat.

Exp. The intense action of the cause will sufficiently account for the sudden effect, and the removal of a portion of the ethereal matter between the atoms A and B, (*fig.* 20,) shews the cause of the extrication of light and heat.

Ph. 56. Spongy platina produces a like effect.

Exp. The explanation of *ph.* 33, will apply in this case.

Ph. 57. The inflammation of a mixture of hydrogen and chlorine is effected at a much lower temperature than one of hydrogen and oxygen.

Exp. The foregoing explanations shew, that the atmos-

pherules of these substances are readily involved in each other, and hence a low temperature is sufficient to produce the combination of these atoms in their gaseous state.

Ph. 58. The muriatic acid gas is partially decomposed by the action of the electric spark; but in continuing the process of passing the spark, it is reproduced as quickly as it is formed, so that only a partial decomposition can be thus obtained.

Exp. The electric spark, in its rapid progress, may be easily conceived to separate in its passage several of the particles such as AB (*fig.* 23), so as to render them distinct as in *fig.* 20, but some definite number of particles being thus decomposed, the succession of sparks will cause the re-combination of some part of these, according to *ph.* 38, while it decomposes others; hence the progress both of decomposition and combination will be arrested, by being equalized.

Ph. 59. Oxygen and chlorine cannot, by any known means, be made to combine directly, when mixed together in the gaseous form.

Exp. It appears, from *ph.* 29, and 54, that the force of an atom of chlorine is greater than that of oxygen in the ratio of 5 to 2, and that its spherule is also greater, hence the forces of the two atoms at their surfaces will be nearly equal, and therefore (*prop.* 25. *sect.* ii.) they will not easily combine.

Ph. 60. When to a mixture of equal parts of water and strong muriatic acid, and about two parts of chlorate of potash, a gentle heat is applied, a gas is evolved, which may be received over mercury, and is ascertained to be a compound of oxygen and chlorine in proportion by weight as 16 to 72, and hence by volume as 1 to 2. It is called euchlorine or protoxide of chlorine.

Exp. According to the foregoing explanations, particularly those of *ph*. 29, and 54, the particles of euchlorine must consist of one atom of oxygen united with two of chlorine. Hence it will be represented by *fig*. 29, or 44, or by some other like figure. The phenomena of this gas indicate, that *fig*. 44, represents one of its particles. The mutual actions of the muriatic acid and potassa, aided by the water, decompose each other, liberating a portion of their chlorine, and yielding two compounds, *viz*. water, and the protoxide of chlorine, on the principles already explained.

Obs. This substance is generally considered as consisting of one atom of each of its elements, and would in that case be represented by some such figure as AB (*fig*. 25,) but its phenomena indicate, that this is very improbable, as will appear by what follows.

Ph. 61. Euchlorine explodes suddenly and violently by a gentle heat applied to the vessel, which contains it, and by the action of other feeble means.

Exp. Admitting according to *ph*. 59, that the forces of oxygen and chlorine are nearly equal at the surfaces of the spherules, the combination will be feeble, and but of little permanency (*prop*. 25, and *cor*. 2. *sect*. ii.), and this will also appear if we admit, that it is composed as represented in *fig*. 44; for the pressure of ethereal matter, between B and C, on A, will greatly promote the decomposition, which must evidently be effected by a small elevation of temperature; the case being very different from the similar combination of two atoms hydrogen, and one oxygen, since chlorine is 36 times more powerful than hydrogen, and the very great quantity of ethereal matter condensed on the three very powerful atoms, especially about A, by means of their great force, will fully account for the suddenness and violence of the explosion.

Ph. 62. The decomposition of euchlorine shews, that it is composed of two volumes of chlorine, and one of oxygen, the three volumes being contracted into two and a half.

Exp. If the compound gas were represented by *fig.* 29, we should expect that the three volumes would be condensed into two: but it is more probable, that *fig.* 44, indicates the form of the combination, according to the preceding explanations; and we may easily conceive, that the powerful attraction of ethereal matter, by the energetic atoms AC, and B, will prevent the contact of the surfaces of B and C at the center of A; by this disposition the change of volume may be explained, for here B and C will each supply one volume, while A occupies only half a volume.

Ph. 63. "In almost all cases of vivid combustion there is a condensation of the bodies which unite; but in the decomposition of euchlorine by heat, we have the remarkable phenomenon of an explosion, accompanied with heat and light, and yet with an expansion of the elements, which are separated from each other."—Dr. *Henry's* Chem. vol. i. p. 216.

Exp. The explanation of the preceding phenomenon makes the reason of this clear, the separation of A, *fig.* 44, increases the volume; and the dense atmospherule between B and C not only supplies the separate atoms, to support the increased volume, but also liberates abundance of ethereal matter with great force, affording the light and heat.

Ph. 64. There is a combination of chlorine and oxygen which according to Sir *H. Davy* consists by weight of 36 chlorine and 32 oxygen, or in volume as 1 to 2, this, by a gentle heat explodes with more violence, and greater expansion than euchlorine; two volumes of oxygen and

one of chlorine are condensed into two volumes of this compound.

Exp. A particle of such a gas on the preceding principles, would as to the tenacious atoms, be represented by *fig.* 30; now the great force of the atoms of this particle will produce an abundant condensation of ethereal matter on their spherules, also the combination will be slender, partly on that account, and the decomposition will consequently agree with the effects of the explosion and expansion.

Ph. 65. Oxygen and nitrogen gases put together in any proportions do not under common circumstances combine, but constitute a simple mixture.

Exp. This applies in most cases when the mixture consists of simple gases, and is agreeable to the theory and principles explained.

Ph. 66. Oxygen and nitrogen may be made to combine in several proportions, the compound, containing the least proportion of oxygen, is constituted by weight of 16 oxygen and 28 nitrogen, or, in volume, one oxygen to two nitrogen, and the three volumes, when compounded, become two volumes of a gas called nitrous oxide.

Exp. From the phenomena connected with these substances, I conclude, that the spherule of nitrogen is greater than that of oxygen, *fig.* 29 may represent the combination, C and B being atoms of nitrogen, it differs from steam in the force of the atoms of nitrogen, and perhaps some little in the extent of its spherule. One volume is here condensed from the interior situation of the oxygen which is inclosed in the others.

Ph. 67. A second compound of these elements, called deutoxide of nitrogen or nitrous gas, consists of equal volumes of oxygen and nitrogen, retaining the same volume in the combined state.

Exp. This may be represented by *fig*. 45, the small circle representing the spherule of oxygen: it is in some respects similar to the combination of chlorine and hydrogen *ph*. 54, and following, and may be conceived to be formed after the same manner. Hence, as in that case, there will be no condensation, but a difference of nature, in consequence of the difference in the absolute and relative forces of the atoms, and magnitudes of their spherules.

PH. 68. Another gaseous compound of these elements, called nitrous acid, is well known; it consists of two volumes of oxygen, and one of nitrogen, condensed into about one volume.

Exp. Under several circumstances, we may suppose such a compound formed, its elements being duly presented to each other; and taking as before the spherule of nitrogen to be nearly equal to that of hydrogen, *fig*. 46 will represent its particle as to the tenacious atoms, the number of atoms in simple gases being as the volumes, (*prop*. 25. *sect*. ii.): two atoms of the oxygen will be combined, with one of nitrogen, the action of the nitrogen will partly remove the ethereal matter from the interior surfaces of the oxygen, hence their spherules will attain their position at the center of the nitrogen, so that two volumes or nearly two will be condensed, the three volumes of gas becoming one or nearly one.

PH. 69. The nitrous acid (*ph*. 68) is slowly produced, by passing a succession of electric sparks through a mixture of oxygen and nitrogen; it is also obtained, with other products, by passing the electric spark through nitrous oxide (*ph*. 66), or nitrous gas (*ph*. 67).

Exp. That the almost instantaneous action of the electric spark on the mixed, or combined elements, which lie in the line of its rapid passage, should force many of the

atoms into a position similar to that of *fig.* 46, is a circumstance, which the theory would lead us to anticipate, and perhaps this is the most permanent of the simple compounds of these elements.

PH. 70. Hydrogen does not unite directly with nitrogen, when the two gases are simply mixed together; but when it is presented in a nascent state to nitrogen, it will unite with it forming a gaseous compound, such that two volumes contain one volume of nitrogen, and three of hydrogen, this compound is called ammonia.

Exp. Simple gases seldom unite by mere mixture (see *ph.* 59 and 65), but hydrogen, when immediately liberated from certain compounds, may combine with the adjacent atoms of nitrogen when such are present (see *ph.* 54), the relation of the spherules and forces may be such, that even three atoms of hydrogen shall unite with one of nitrogen, and be necessary to the support of the combination constituting an atom of ammonia.

A particle of this compound may be represented by *fig.* 47, the atmospherules of ethereal matter being supposed to be applied according to circumstances, and here n is to denote the nitrogen, h, h', h'', the three atoms of hydrogen, the nitrogen is condensed from its internal situation, and, since the three centers are in the surface of the nitrogen, we may fairly suppose, that one third of the spherules of hydrogen are involved within it, and condensed, which will give the known contraction of volume.

PH. 71. Ammoniacal acid gas has a very strong pungent smell.

Exp. If the constitution of ammonia be as above explained, and represented in *fig.* 47, it is evident that the atoms of its hydrogen will, by means of very slight causes, oscillate on the central atom of nitrogen, and this will affect the atmospherules, several particles will be

occasionally decomposed, and the atoms of hydrogen, if not of nitrogen also, and perhaps even entire particles of ammonia, will be projected on all sides, and this will produce the smell and pungency of this gas.

Ph. 72. Ammoniacal gas is decomposed by a succession of electrical sparks, it occupies a double volume when decomposed.

Exp. The electric spark, in its rapid motion, is sufficient to force the hydrogen to one side, and to separate some portion of it, in consequence of which the decomposition is effected. According to *ph*. 70, the volume of the decomposed gas ought to be double.

Ph. 73. When ammonia is passed through red hot porcelain tubes it is decomposed,

Exp. A little attention to *fig*. 47, will shew, that, when exposed to a great heat, its elements will be easily separated; for the central atom being about 14 times stronger than the others, the caloric will be urged between every two adjacent sides of the hydrogen, and at a certain degree of intensity will necessarily effect their separation.

Ph. 74. The volumes of gases, entering into combination, are generally in very simple and definite proportions, as one with one, or with two, or three, &c. this fact was first pointed out by M. *Gay-Lussac*.

Exp. In simple and in many compound gases, this will be the necessary consequence of the simple proportions in which the atoms combine, see *ph*. 29, 54, 62, and 70. For these phenomena and the theory will be sufficient to shew that, in simple gases, equal volumes will contain the same number of atoms; and in compound gases, the volume will contain either the same number of particles, or one half as many, or one third as many, &c. For according to the phenomena above referred to, the contractions will, in most cases, be none, two thirds, one

third, &c. the resulting volumes of the combination (*ph.* 53) being also generally in simple ratios, hence the combining volumes ought to be in very simple proportions.

Ph. 75. When gases unite, the condensation is generally in some simple ratio to the original volume: but sometimes there is a considerable variation from this rule.

Exp. The reason of this was shewn, *ph.* 53, and will appear by the last phenomenon and the references there made, but that there may be instances of great differences will be seen by a consideration of *ph.* 60 and following.

Sch. The preceding examples may suffice to shew the application of the theory to the combinations of gaseous substances.

The explanations given are considered as being very probable, and, although they may not be absolutely the true ones, yet they will serve particularly to shew, that at least these phenomena are not opposed to our principles.

To estimate the relative magnitudes of atoms has, as yet, been found a problem too difficult to be solved, even in our present advanced state of knowledge. This however is a desideratum, it is a subject which many have investigated, and should these labours rest on a solid foundation, it is presumed that the way is a little opened towards the cultivation of this field of science, which presents the prospect of a rich produce, and an abundant harvest.

Ph. 76. Many bodies require an elevated, or some particular temperature, in order to effect their combination: thus carbon and hydrogen, when made hot, readily combine with oxygen, but not so at the usual temperature.

Exp. When the temperature of a body is raised, the atmospherules of its particles are augmented, and greatly extended: hence in many cases the atoms of another body

may be more easily involved in them, a circumstance tending to facilitate the combination: thus when the atmospherule of an atom of carbon, or of hydrogen, and one of oxygen are much increased, and extended, an atom of oxygen pressed near the carbon or hydrogen will be more readily enveloped in the same atmospherule, and combination will be effected, because part of the atmospherule, greatly extended on every side, mixes at once with that of the oxygen, and the vibration itself, which is produced, contributes towards this union.

Ph. 77. When bodies combine, there is often not only a change of properties and temperature, (see *ph.* 11, and 14), but also such a change of form, that one or both of them appears to be destroyed, or consumed: thus when a mixture of oxygen and hydrogen gases, one volume of the former, and two of the latter, combine, they both disappear as gases, the only product being a small quantity of water, occupying nearly two thousand times less space than that which the gases occupied.

Exp. In many cases of combination, as in the instance here given, much ethereal matter is dissipated, the new arrangement of the atoms, not being capable of the gaseous form at the usual temperature, and the particles are consequently suffered to approach each other, and hence they occupy but a very small space in the liquid or solid form. In other cases, the products retain their atmospherules, and may be suffered to escape as gas or vapour; hence the combining bodies are indeed consumed, or destroyed, as such, but the materials remain unchanged in themselves; that is, their atoms remain the same, although concealed under new forms.

Ph. 78. Combustion frequently occurs when a remarkable change is produced in bodies by chemical action, as when oxygen combines with hydrogen, or carbon, &c.

Exp. The notable change, resulting from the chemical action, indicates, that one or both of the elements concerned is constituted of powerful atoms, which consequently condense on their spherules large portions of ethereal matter; also when the union takes place, rapid and quick vibrations are necessarily produced; hence much ethereal matter will be projected with great energy, radiating in the form of heat and light.

Ph. 79. The most common or general cases of combustion occur, when oxygen combines with various bodies, called combustibles; as coals, wood, oil, tallow, &c.

Exp. The substances enumerated and such like, contain large proportions of carbon and hydrogen, these at an elevated temperature readily combine with oxygen (*ph.* 76), and an atom of oxygen has great force (*ph.* 29 and 54), therefore by *ph.* 78, combustion ought to take place, and the more so, on account of the high temperature of the combustible. Even many of the metals themselves burn vividly, when raised to a very high temperature, oxygen being present.

Ph. 80. Chlorine and iodine are also remarkable for exhibiting the phenomena of combustion in many of their combinations.

Exp. The atoms of these substances evince in their several actions, and combinations with other bodies, that they are constituted of great forces, which renders them suitable for exhibiting the appearances of combustion, as above in the case of oxygen.

Ph. 81. As a familiar instance of combustion, it may be observed, that when a candle is lighted, it continues to burn with great regularity, if properly snuffed, till it is consumed, giving out a constant supply of heat and light.

Exp. The wick by being lighted, has its temperature

sufficiently raised to admit a speedy union of its carbon and hydrogen with the oxygen of the air, the chief part of the products are dissipated in vapour; the ethereal matter evolved (*ph.* 78 and 79) raises the temperature still more, and melts the tallow immediately below it, the melted tallow, by capillary attraction (*ph.* 20. *sect.* v.) rises in the wick, where the degree of heat is so intense as to render it gaseous, and in this state, as it rises, it unites with the oxygen situated on every side of the flame in its course, so that the exterior surface of the rising gas, which is in contact with the air, enters rapidly into combination with the oxygen of the atmosphere, the ethereal matter evolved, from the tallow rendered gaseous by heat, and from the oxygen which combines with it, supplies a body of light (*ph.* 78, 79) and also of heat, sufficient to maintain the temperature, and to melt the tallow, so that the process is continued. The candle wastes away or is consumed by this process, because its particles when united to the oxygen are dissipated in vapour. In a similar way may the burning of many bodies be explained.

Ph. 82. Bodies burn in oxygen gas as in common air, but with vastly greater vividness and brilliancy.

Exp. Oxygen constitutes but about one fifth part of the air, the rest being chiefly nitrogen, which does not easily combine, and hence impedes the process, so that the effect cannot be so rapid as when the combustible is surrounded by a body of pure oxygen gas.

Ph. 83. Bodies will burn vividly in oxygen gas, which will not burn, under the same circumstances, in the open air; thus, if a small bit of tinder be attached to the extremity of a thin iron wire, and then lighted, and immediately plunged into a vessel of oxygen gas, it ignites the wire, which burns till the iron or oxygen is consumed, but in the open air the iron is not ignited.

Exp. In the open air there are not, in contact with the lighted tinder, a number of atoms of oxygen sufficient to unite with the tinder, so as to raise its temperature, and that of the contiguous iron to the degree which is requisite for the rapid combination, or the burning of the iron; but in the oxygen gas the great number of atoms in contact with the lighted tinder, immediately uniting with the combustible body, send forth a copious supply of ethereal matter adequate to produce the combustion of the wire, and the same reason accounts for the continuance of the burning.

Ph. 84. In chemical action, generally, and consequently in combustion, when the temperature is raised, there is very frequently a condensation; thus oxygen and hydrogen are condensed into water, oxygen and carbon into carbonic acid gas.

Exp. In these cases the product is such as can exist only in that condensed state at the common temperature, the new particle having new properties; also other things being the same, the condensation causes a greater quantity of caloric and light to be evolved in the combustion.

Ph. 85. But sometimes there is an enlargement: thus protoxide, and deutoxide of chlorine, burn by the application of a gentle heat, the substance is destroyed with violence, and the emission of heat and light, and its elements may be obtained, as a mixture of oxygen and chlorine.

Exp. This is sufficiently explained in *ph.* 61, 62 and 63, the protoxide being represented in *fig.* 44, and the deutoxide in *fig.* 30; much ethereal matter is condensed on the combined atoms, *viz.* on the oxygen, because of its great force, and small spherule, and on the chlorine, because, although its spherule is probably greater, its force

also is greater even than that of oxygen; also the manner of the union of these atoms will cause an additional accumulation of ethereal matter on the particle, these circumstances as seen in *ph.* 60, and those just referred to, account for the rapidity and violence of the action, and for the extrication of the heat and light, with the increase of volume.

Ph. 86. When gunpowder is ignited, it burns with great rapidity, and is expanded into a gas, with the extrication of heat and light.

Exp. Five parts of nitre, one of sulphur, and one of charcoal, being finely powdered, and then mixed well together, with a little water to prevent explosion, constitutes gunpowder, when it is granulated by pressing it through sieves, and carefully dried. Now, according to the determinations of chemists, each particle of nitre contains six atoms of oxygen, besides nitrogen and potassium; from one pound of nitre 12,000 cubic inches of oxygen gas may be obtained on distilling it in an earthen retort, made red hot, therefore it must condense much ethereal matter, which doubtless is greatly increased by the manner of combination of the atoms of nitre, as appears from this, that it is found to retain a part of its oxygen very loosely: we may judge therefore, that it is connected in a way calculated to retain much caloric, light, &c. as in the protoxide and deutoxide of chlorine (see *ph.* 61, 62, 63, and 85). Sulphur also, as appears from many phenomena contains much caloric on its spherules, hence, when ignited, it happens, that through the medium of the rapid union with the charcoal, the abundant mass of ethereal matter liberated, is sufficient to render the products gaseous, even under a great pressure, hence heat and light are necessarily projected in the process.

The circumstance of expansion of the products in combustion, has hitherto been considered as inexplicable, (see *Turner's* Chemistry, p. 155 and 156.)

Ph. 87. Chlorate of potassa may be substituted for the nitrate in making gunpowder, but very great caution is requisite in the preparation, as the ingredients are very liable to explode; a mixture of sulphur and this salt has been known to explode spontaneously.

Exp. In each particle of the chlorate is combined an atom of chlorine, instead of one of nitrogen, which is in the nitre, and this constitutes their difference, the other parts being the same, and from the greater force of the atom of chlorine, we should be led to anticipate a greater liability of the composition to explode.

Ph. 88. If two grains of powdered chlorate of potassa be mixed with one of sulphur, and the mixture be gently triturated in a mortar, a series of detonations will ensue, resembling the cracking of a whip: if struck on an anvil, the report is as loud as that of a gun.

Exp. The mechanical action produces the decomposition at one or more points, and the effect is propagated to the neighbouring parts: the rest is as above.

Ph. 89. If with a small quantity of sugar, half its weight of the powdered chlorate of potassa be mixed, and on the mixture be cautiously poured a few drops of strong sulphuric acid, it will burst into sudden and violent inflammation. This mixture is the basis of the matches used for obtaining instantaneous light.

Exp. The combination of the acid with the sugar will raise the temperature sufficiently to produce the decomposition of the chlorate of potassa, and this gives rise to the sudden inflammation.

Ph. 90. If about half a table spoonful of strong nitric acid, mixed with a very little sulphuric acid, be poured on

which compose the vegetable; and hence it is rendered devoid of colour, and is not in a condition suitable for combustion in the strict sense.

Ph. 97. The quantity and colour of the light in combustion, depends chiefly on the combustible body.

Exp. This may arise from the sort of light which the combustible most copiously condenses in the atmospherules of its particles; for according to the differences of the particles of the body and of the ethereal matter, more or less of the different sorts will adhere to and unite with the particles.

Ph. 98. Carbon, sulphur, phosphorus, and the metals unite readily with oxygen under certain circumstances, and exhibit the effects of combustion, during the combination.

Exp. All that is necessary for these actions and results, is a suitableness in the spherules and forces, with their atmospherules of ethereal matter, and a proper degree of temperature, and proximity to favour their union, as shewn in various of the foregoing phenomena, under these proper circumstances the bodies unite and lose part of their atmospherules.

Ph. 99. When equal quantities of oxygen are consumed in combustion, it is found according to the experiments of some chemists, that metals, and phosphorus emit about twice as much heat as hydrogen; and charcoal about $1\frac{3}{20}$ as much as hydrogen.

Exp. The greater heat produced in one instance than in another may arise, from the greater quantity of ethereal matter contained on the atoms of the combustible body, or from the more forcible and intimate union in the one case than in the other, which arises from the different nature of the atoms or particles.

Ph. 100. If phosphorus be exposed to the common air

at the usual temperature, it emits a white vapour, a smell like that of garlic; it appears luminous in the dark and is gradually consumed. This is called the slow combustion of phosphorus.

Exp. The atoms of phosphorus at the common temperature are capable of combining with the oxygen of the air, the particles formed by this union will be sufficient to account for the vapour or smoke which rises, and the light is produced in consequence of the ethereal matter which is made to radiate at the moment of combination, in consequence of the repulsion between its atoms and that of the particles of the body which are brought near each other, and then, because of their proximity, are consequently repelled with great velocity.

Ph. 101. The metals require different temperatures to effect their combinations with oxygen, some of them absorb that substance rapidly at common temperatures, others but slowly, and some only at high temperatures; others again require different conditions in order to make them combine with oxygen, and are again reduced to the metallic state by heat alone.

Exp. There is here no greater variety in the effects than the differences in the forces and spherules of the atoms of matter would suggest, hence these different effects are natural and easy to understand.

Ph. 102. Rough filed iron unites much more readily with oxygen, than well polished iron.

Exp. When the iron is well polished the surface is uniformly covered by ethereal matter diffused over it, (*prop.* 17, and *cors.*) and this tends to prevent the accession of the atoms of oxygen; but when, by filing the surface presents abundance of asperities, the ethereal matter will be protruded at their extremities (*prop.* 17, and its *cors.*), hence the oxygen has access between the points and more

readily combines with the iron, the ethereal matter in this case contributing to accelerate the combination. There are many similar phenomena, which are to be explained on the same principles.

In this and the two preceding sections are explained two hundred and twenty phenomena, which include the most general cases of Chemistry, many thousand particular instances might have been adduced, but they would be found to belong to some of those already considered, or to have a close affinity to them; and it will be unnecessary to swell this volume by entering more at large into the particular cases of combination and decomposition. If what has already been advanced, be attentively considered, the reader will be able himself to apply the principles to such examples as may occur.

SECTION VII.

ELECTRICITY.

Observations relative to Electricity.

Electricity is a term employed to designate a branch of physics, which has respect to an extensive class of phenomena, arising from a property which bodies acquire in certain states, and under certain circumstances, in which they attract neighbouring light bodies, emit luminous sparks, inflame combustibles, give out intense light and heat, and produce many other effects on the bodies submitted to their actions. Nothing was known to the ancients of this department of science, except that amber, and perhaps one or two other substances, when rubbed, attract light bodies; it was reserved to the moderns to unveil in an extensive degree the workings of nature in respect to electric powers or energies. This science is of great importance in philosophy, and deserves the continued efforts of the learned to develope what still remains undiscovered in relation to

its extensive agency. It has been already stated in the Introduction that as electricity advanced from its infancy towards that degree of maturity to which it has arrived, many electric theories were proposed and again discarded, with the exception of two or three, *viz.* The *Franklinean* theory of one fluid modified and improved by *Epinus*, and that of *Du Fay* adopted and more clearly stated and applied by M. *Columb;* see the Introduction. To these we may add a theory of more modern date, which ascribes electrical effects to some supposed peculiar exertions of the attractive powers of matter. This theory regards the existence of any distinct fluid or form of matter to be as unnecessary to the explanation of the phenomena, as it is in the questions concerning the cause of gravitation. But surely it would be extremely difficult to shew how these peculiar powers can be transferred from one body to another without the transmission of some fluid or material substance at the same time : and it would be equally a task to explain on this hypothesis how the electrical energies of bodies can be increased, and diminished, and changed from one state called the positive, to the opposite or negative.

After all the labours of philosophers in these regions of theory, we have obtained nothing satisfactory. "We have as yet no plausible hypothesis concerning the *cause* of electrical phenomena, though the subject has engaged the attention of the most eminent philosophers of *Europe.*" (*Brande's* Manual of Chemistry, vol. i. p. 283.) In truth I am persuaded that all the electrical theories which have been brought into notice, and all those which can be proposed as requiring something peculiar in the production of electricity are not better founded than castles in the air. If the time, which has been spent in forming and modelling and remodelling these theories, had been em-

ployed in trying to deduce electrical effects from the powers known to affect the particles of matter, the causes of these appearances would at this day have been more fully exhibited; that a fluid is concerned in all electrical actions there can be no doubt, (see the observations at the commencement of the fourth section); and this fluid may properly be termed the electric fluid: but it is not at all requisite to give to its atoms peculiar and distinct properties, differing essentially from those of other matter. I shall therefore in this section proceed to explain the principal electrical phenomena independently of any electrical hypothesis, employing no other but the general theory of physics already advanced, trusting that the explanations will be found more satisfactory than those which rest on any of the received theories; and that several facts will be explained, which it is acknowledged are amongst the arcana of nature.

Electrical appearances are excited by different means, as by friction, communication, the contact of dissimilar bodies, heat, change of form, and the like.

When two suitable substances are rubbed one by the other, both become electrical, but they are found always to be in different states, each will indeed attract light bodies if presented separately, but if both be presented at the same time no effect is produced; also what has been attracted by the one will be repelled by the other; hence though both are excited a remarkable difference is experienced. One of these bodies we say is electrified positively, and the other negatively, or the one is in a positive, and the other in a negative state. These terms are employed agreeably to the *Franklinean* theory, which supposes, that, when the bodies are rubbed together or otherwise excited, the one acquires an additional quantity of the electric fluid and is said to be positive, and the other is deprived

of a like portion, and from its defect is said to be negative. Dr. *Franklin's* theory in this respect agrees partly with the notions that result from our general theory of physics, and hence these terms will be still employed in the same sense, and evidently with the same propriety; for we still have an electric fluid, though its properties are not such as those which are ascribed to it by the adherents of *Franklin*. But a body, according to our notions, is said to be positive or negative, not merely on account of its containing a greater or less quantity of electric fluid; but it is said to be positive, when from any cause or circumstance it is in a condition such as is suited to give out a portion of its fluid to the adjacent bodies: and on the contrary it is said to be negative, when it is in a state disposing it to receive a portion of the electric fluid from the contiguous bodies, Now these conditions may arise, not only from an actual acquisition or loss of their natural fluid, but also from the distribution of the fluid on the several parts of the body, and also on the sides of its several atoms; for the ethereal matter constituting the electric fluid, forming part of the atmospherule of each atom, may from various causes (*prop.* 17, and its *cors.*) be extended more on one side of the atoms and less on the other, hence in this case each atom will have a negative and a positive side, and the whole body will on this account also have a negative and positive extremity. These particulars agree perfectly with facts which have never yet been accounted for, except by means of suppositions and terms employed to conceal our ignorance. Let it be further noticed, that the negative and positive electrical states of bodies may be induced also by the relative quantities of their fluid, although all the bodies may contain the fluid, in defect or in excess.

In order to fix the meaning of the terms positive and

negative, as employed in electricity, and particularly in this Treatise, it may be proper to give an example by way of illustration. Thus, if smooth glass be rubbed with silk, both become electrical, and will attract and repel bits of straw, feathers, and other light bodies. An insulated light body which has been first attracted, and then repelled by the one, say the glass, will continue to be repelled by it, but will be attracted by the other. The glass in this case is said to be positive, and the silk negative: also any body is said to be positive, when it agrees with the glass in repelling the body, which has been repelled by the glass, and it is said to be negative, when it agrees with the silk by attracting the body which has been repelled by the glass. There are good reasons for concluding that, during the process of friction, the glass has received a portion of electric matter, from the silk, on which account the above distinction is made, and it is introduced here for the sake of giving a distinct idea of the terms.

How it may be known when a body is electrified positively or negatively, will appear from the phenomena relating to electrical attraction and repulsion to be explained in this section.

Diffusion of the Fluid.

PH. 1. The principle, whatever it may be, which produces electrical phenomena, is universally diffused throughout the material world, having been noticed in all kinds and forms of bodies, and clearly evinced by an innumerable multitude of experiments and observations.

Exp. Ethereal matter of all kinds, constituted accord-

ing to the first postulate, and designated in *def.* 32, if existing in sufficient quantity, will tend to universal diffusion, while the centers of its atoms are in each other's spherules, and its constituent forces may be so small, and the extent of its spherules such, that it shall answer to the description of light, caloric, and the electric fluid, according to the differences in its spherules and constituent forces, it will adhere to the atoms of bodies, and may be transmitted from one body to another with greater or less facility according to circumstances, hence one species of it may be capable of producing the electrical phenomena, as a little reflection will shew, and as will appear from the following explanations. It is probable that the spherules of its atoms are less, and its constituent forces greater than those of light and caloric. We denominate this species of ethereal matter, the electric fluid.

Ph. 2. When two bodies of different kinds are rubbed together, under proper circumstances, both become electrical; but always the one is positive, and the other negative.

Exp. Both the bodies are at first imbued with the ethereal matter, which we call the electric fluid, so as to be in a state of equilibrium with each other, and with the surrounding bodies, also this fluid, which may be said to be natural to them, will be most diffused over the surfaces of the bodies (*prop.* 17, and its *cors. sect.* ii.), hence when they are rubbed together, partly from the difference in the surfaces, and partly from that of the sort of bodies, the connection of their parts, their degrees of hardness, &c. it is to be expected, *a priori*, as a natural consequence, that a portion of the fluid of the one will pass to that of the other, and hence, when separated, the one will be disposed to part with some of its fluid to the surrounding bodies, and the other to receive a portion. Hence both

are excited, there is a tendency, in both cases, of the electric fluid to pass between either of them, and such bodies as are in their natural state, and so far similar effects will occur: but a marked difference will arise from this circumstance, that the fluid tends to leave the one body, but to enter the other. When they are put nearly in contact they destroy each other's effects, because now the fluid tends to pass from the one to the other, rather than to the adjacent bodies.

PH. 3. If a dry smooth glass tube be rubbed with a piece of dry woollen cloth, the tube is rendered positive, and the cloth negative.

Exp. The electric fluid strongly adheres to glass, as will be seen in some of the following phenomena, hence it will receive a portion of the fluid from the more yielding and fibrous cloth, and thus will become positive, while it leaves the cloth in a negative state.

PH. 4. If a dry glass tube, whose surface has been rendered rough by grinding with emery, sand, &c. be rubbed with a dry woollen cloth, the tube will, in this case, become negative, and the cloth positive.

Exp. The electric fluid adheres strongly to the glass, and hence it will contain much of that fluid, as its natural quantity, and since the surface presents an innumerable multitude of points, these points will be fraught with the electric fluid, (*prop.* 17, and its *cors.*) it follows that the cloth will easily now take, or, if we may so speak, wipe off much of that fluid from the projecting points, and hence the glass is rendered negative, and the cloth positive.

Obs. This and the two preceding phenomena are introduced in this place, for the sake of giving a more easy explanation of the following ones; the subject of excitation will be more fully developed in due order. The elec-

tricity induced on a smooth glass tube when rubbed with flannel or silk is called positive, because many phenomena shew that in this case it receives an increase to its natural quantity of electric fluid.

Ph. 5. If the electric virtue be excited in one body to a certain degree, and another body be brought into contact with it, the body presented will receive more or less of the electrical influence.

Exp. Let A and B, *fig.* 50, be two bodies, on which, as well as on all the surrounding ones, such a proportion of electric fluid is diffused, that they are in a state of equilibrium amongst themselves, and, in this case, it is evident there can be no disposition or tendency of the ethereal matter to pass from the one to the other. Now let a sufficient quantity of the fluid be communicated, by some means, to A, and diffused over its surface, the atmospherules of its particles will be extended, and will press outward (*prop.* 27, *sect.* ii.) and will therefore tend to pass off to any body, suppose B, connected with the earth and placed near it, and much more when in contact. On the contrary let a sufficient quantity of fluid by some means be abstracted from A, the atmospherules of its particles will be diminished, and those of the surrounding bodies will tend towards it, (*prop.* 28, *sect.* ii.) and hence it will be in a state ready to receive the electric fluid, from any body, as B, in its natural state, and to which it is contiguous. Hence in the first case an adjacent body in contact will become positive, in the second case, negative.

Conductors and Non-conductors.

PH. 6. Some bodies will receive and retain the electric virtue at and near the part to which it is communicated, and these are called non-conductors; such are resins, sulphur, glass, silk, wool, dry air, and other gases, dry paper, baked wood, oils, dry metallic oxides, &c.; again other bodies suffer the electric fluid to be diffused with more or less facility and rapidity over their several parts, such are called conductors, among which are the metals, charcoal, acids, water, and moist bodies, &c.

Exp. As it was shewn, that, in cases of cohesion, and of chemical affinity, some atoms or particles adhere or combine with more freedom and firmness than others, so, for the same reason, the electric fluid, or ethereal matter in general, will more readily adhere to, or unite with, the atoms or particles of one body, than with those of another, in consequence of differences in the atmospherules retained by the particles or atoms of the body: also from the connection, closeness, and relative position, of the tenacious atoms, which compose different bodies, as well as from their different forces, and extent of their spherules, the electric fluid will more completely diffuse itself around the particles of the one, than about those of the other, and will more firmly adhere to them. Now let A and B, *fig.* 66, be two bodies, the quantum of their fluid being such that they are in equilibrium with each other, and with the surrounding bodies; and let the electric fluid be confined to A, till it has a given tension, or tendency to escape, (which may take place by *prop.* 27, *sect.* ii.), so that when B is brought into contact it will receive a portion of the fluid at the touching point: now if the

particles of the body B, be such that the fluid can easily unite with them, and adhere firmly, and especially if it can freely diffuse itself about the several particles, on most of their sides, the fluid will be retained on those particles to some limited degree, suppose that to which A is charged, and hence it will not be distributed over the body; let now the quantity, and consequently the intensity, of the fluid of A be increased, more of it will then pass to B, and will spread to the particles surrounding the point of contact, and by its adhering to these particles will support a greater quantity on the particles which are at the place of contact, and thus an equilibrium will be again produced, and no more can pass from A to B, till the intensity of A be still further increased, and if this be done, more fluid will again pass over to B, and will advance on its surface to the next adjoining stratum of particles, which, receiving additional atmospherules, will support a greater quantity at the place of contact, and thus, as the quantity and consequently the intensity is increased on A, the fluid will be propagated further on B, till its intensity, at the point of contact, is equal to that of A, and this distance will be greater or less, as the atoms of the electric fluid attach themselves less or more firmly and copiously to the separate particles of B; when the force retaining the fluid is greatest, the substance B forms the best non-conductor; and as the retaining force is less, the passage of the electric fluid is resisted with less energy. When the atoms or particles of B do not firmly retain on them the communicated electric fluid, either from their weak attraction, or from their closeness of union, so that their usual or natural atmospherules are diffused and intermixed, the substance B will be a good conductor; for as the fluid is transmitted from A to B, it is immediately diffused over its whole surface, by the re-

pulsion between the atoms of the electric fluid, for while attached to bodies or forming atmospherules, the centers of the ethereal atoms are in each other's spherules, as has been already abundantly shewn. Next, instead of communicating the fluid to A, let a portion of its natural quantity be removed, and then let it be placed in contact with some part of B, it will follow from the above reasoning, that if B have the properties of a non-conductor, as just described, it will part with its fluid only at the point of application, and at the neighbouring parts to a less or greater distance, according as the diminution in A has been less or greater, and as the conducting property is greater or less; and hence when B is a very good conductor, it will by the contact of A be deprived of a portion of its fluid from all parts of its surface.

Ph. 7. There is no precise line of distinction between non-conductors and conductors; but bodies are found in all intermediate degrees, from the best non-conductors to the best conductors, and there are none absolutely perfect of either class.

Exp. This follows plainly and clearly from the foregoing explanations, for all variety of difference will arise, not only from the different nature of the bodies, but also from the degrees of the electricity.

Ph. 8. Many bodies, which are non-conductors to electricity of weak intensity, are conductors when the intensity is greatly increased, and all bodies conduct electricity of very great intensity.

Exp. This also is agreeable to the explanation of *ph.* 6, from which it is an immediate deduction, and evidently when the whole surface of a body has the fluid diffused over it, it will conduct electricity readily.

Ph. 9. If cylinders formed of glass, gum-lac, or wax, be presented to a strongly electrified body, it will be

found, that the electricity is propagated to a certain length with decreasing intensity. *Biot's* Physique, vol. ii. p. 244.

Exp. To these substances the electric fluid strongly adheres, and therefore it will be received readily at the place of contact, and retained there, passing only to a small distance, more or less according to the intensity of the electrified body, the *exp.* of *ph.* 6 will render this clear. When the non-conductor is short, it will therefore be a conductor to powerful electricity.

PH. 10. Non-conductors, when wetted with water, become conductors.

Exp. This happens in consequence of the water, which in this case is the conducting body. Hence damp air, and wet glass, are conductors.

PH. 11. Many non-conductors become conductors, when greatly heated, as red hot glass, melted resins, &c.

Exp. For their usual atmospherules consisting of ethereal matter, as caloric, light, and electric fluid, become greatly extended and intermixed, from the addition of the caloric, by which the bodies are made hot, and hence the communicated electric fluid cannot adhere to the particles separately of the heated bodies, which consequently become conductors, as the explanation of *ph.* 6 will render manifest.

PH. 12. Dry air continues in some degree to be a non-conductor when it is heated.

Exp. In this case the atmospherules of the atoms of air continue distinct, and sufficiently near each other to retain the communicated fluid; therefore the conducting property is not entirely destroyed; the electrified atoms attaining the intensity of the body, which gives out the electricity, and to which they are contiguous, will prevent its further progress.

PH. 13. Air greatly rarefied becomes a conductor.

Exp. The atoms of the air greatly rarefied will stand at a comparatively great distance from each other, and the several atmospherules will be much extended, and ethereal matter diffused amongst them; hence the electric fluid will find but little resistance to its passage, and by the repulsion between its atoms will be transmitted among the particles of air from one to another with facility.

Ph. 14. In rarefied air an insulated conductor loses its electricity rapidly, but a non-conductor loses it slowly. *Biot's* Physique, vol. ii. p. 213.

Exp. The electric fluid is retained on conductors by a very feeble force, according to what has been advanced, and hence when placed in rarefied air, which is a conductor, it is dissipated speedily by the mutual repulsion between its atoms, but the constituent atoms of non-conductors retain the electric fluid with greater force, (*ph.* 6), and therefore from these it will be given out but slowly.

Ph. 15. A perfect vacuum of a large diameter, surrounded by a non-conductor, is a non-conductor: but when the diameter is small, as that of a fine tube of glass, it is a conductor.

Exp. For since the electric fluid cannot pass along the surrounding envelope, that being a non-conductor, and since there are no tenacious atoms in the vacuum to support attenuated atmospherules, the fluid must adhere to the part of the non-conducting vessel, to which it is presented, forming an extended atmospherule within the vacuum, which is here supposed to be sufficiently capacious, so that the interior atmospherules of electric fluid, do not meet from opposite sides, since the repulsion between the atoms extends to a small distance. But the vacuum will be a conductor when it is very small,

a [illegible] for the electric fluid will, [illegible] and afford [illegible] as it continues to be communicated.

Pr. 16. When a conductor is insulated, that is, when it is supported by non-conductors in dry air, if electric fluid be communicated to it, this fluid will be diffused over its surface, and [illegible] there a long time.

Exp. Since the conductor is in contact with non-conductors only, the electric fluid communicated to it, and [illegible] diffused over its surface, (pr. 6.) cannot be [illegible] away, and will therefore be retained on its surface some considerable time.

Pr. 17. When an electrified conductor is globular, the fluid is equally diffused on its surface.

Exp. There is no known cause why it should be otherwise, the attractions, repulsions, and pressures, are on every side alike, and the body yields no resistance to its diffusion because it is a conductor.

Pr. 18. When an insulated conductor, not globular, is electrified, the electricity is unequally diffused on its surface, being most dense on the smaller extremities, and if it be electrified in different degrees at different times, the relative quantities, at the same points, continue the same.

Exp. First a proportionately greater surface is exposed at the projecting extremities, also the repulsive forces between the ethereal atoms cause them to tend towards those prominent parts, (*prop.* [illegible] and *cors. sect.* ii.) and the surface being given, when more fluid is communicated the same relation of the quantities at each part must remain, because the same relation of circumstances continue.

Pr. 19. If an insulated non-conductor be rendered electrical, it will retain the virtue much longer than a conductor in similar circumstances.

Exp. Since the electric fluid adheres much more firmly to a non-conductor than to a conductor, it follows, that under similar circumstances in other respects, it will be much longer retained on its surface, as it is found to be in fact.

Ph. 20. The earth is the grand reservoir of an immense body of the electric fluid, large quantities of it being easily derived from that source, and returned to it again, a fact well known to electricians.

Exp. Since from the vast number of conducting bodies dispersed through the terraqueous globe, and the almost universal presence of moisture in its different parts, it is, being taken altogether, a conducting body, and being globular, the electric fluid will be diffused in great abundance over it, especially at its surface, in quantity sufficient to maintain the equilibrium of the air, and all terrestial bodies, and there will be a continual tendency to an equal diffusion.

Ph. 21. The atmosphere contains a large proportion of the electric fluid, as is evident from many electric phenomena observable in the region of the air.

Exp. The air contains an abundant quantity of caloric, and light, in order to support its elastic form, and for similar reasons, it will be replete with other ethereal matter, such as the electric fluid which, as well as caloric, it yields when submitted to pressure, and to other processes; if, as is probable, the spherules of the electric fluid be less, and the force greater than those of caloric, it will adhere more closely to the atoms of air, and will form the lower strata of its atmospherules.

Ph. 22. The atmosphere is subject to great changes in its electrical state.

Exp. This naturally arises from the continual variations in the humidity, motions, and pressure of the air,

evaporation and condensation of vapour, and several other causes.

Ph. 23. The electrical equilibrium is sometimes restored to the air by almost imperceptible degrees, but at other times the equilibrium is not attained without great violence, as in the case of thunder storms.

Exp. The former will happen, when the state, and particularly the moisture of the air, suffers an alteration to a very great extent, only by very small and gradual variations: the latter will occur when the differences of the state of the air from clouds or otherwise, are great, in the compass of a moderate extent of space, and especially when there are opposite currents of wind in the upper regions at the same time, for by the friction of these currents electricity is excited and accumulated.

Ph. 24. Bodies armed with points, asperities, and thin edges, either transmit or receive the electric fluid more freely than those which have smooth surfaces.

Exp. For (by *prop.* 17, and its *cors. sect.* ii.) the ethereal matter will be most extended, and intermixed at the extremities of these points, or edges, and hence the electric fluid will readily enter and pass along these parts, when they belong to bodies having a deficiency of the fluid, and as readily pass off by them, when the body has a redundancy.

Ph. 25. Insulated bodies having many points, or asperities, when not in an equilibrium with the surrounding bodies, will sooner be restored to a state of equilibrium, than bodies otherwise alike, and in like circumstances, but having smooth surfaces.

Exp. This follows from the preceding phenomenon, the points either giving out, or receiving the electric fluid, with great facility.

Ph. 26. "There does not appear any definite relation

between the chemical characters of bodies and their conducting powers, for the best conductors (metals) and the best non-conductors (resins and sulphur) are alike inflammable substances. The products of combustion too are dissimilar in this respect, acids and alkalies conduct electricity, but the metallic oxides do not. Neither does it appear that specific gravity, hardness, tenacity, or crystalline arrangement, are connected with the power of electrical transmission, for similar characters of this kind are possessed by both classes. Thus platina, the densest of bodies, is a conductor, but so also is charcoal and rarefied air. Carbonate of barytes has great density, and is a non-conductor, but dry air and the different gases, which are among the rarest forms of matter known, are of the same character. Many non-conductors are brittle; but some are also elastic, and others fluid, and there are bodies of all these classes that are conductors."—*Singer's* Elect. p. 41.

Exp. It will appear from *ph.* 6., that the conducting or non-conducting power will depend on different causes, one of which is the connection of the atoms, or particles, composing the body, a certain proportion of distance, other things being the same, will be most favourable to prevent transmission, and a greater or less distance between the molecules will render them better conductors. They will also be better conductors as the atmospherules of the particles are more attenuated, and extended, also we may add from *ph.* 24, and 25, that when the bodies are more fibrous and furnished with innumerable points, they will tend the more to possess the conducting quality. Now these things being considered, we must conclude, that all the varieties of bodies above enumerated, may be also diversified in the relations of their conducting power, as it is stated they are, and as experiment verifies.

PH. 27. An electrified body loses its electricity much sooner in rarefied than in dense air.

Exp. Each atom of air, holding an atmospherule of ethereal matter, will oppose the tendency of the electric matter to escape; but when the air is rarefied, there will be but comparatively few atoms of air resting on the electrified body, and these will facilitate the dissipation of the electric fluid at the spaces between their points of contact, tending to protrude it from the body, so that the rarefied air acts as a conductor, while the dense air presents an excellent barrier to the extrication of the electric fluid.

PH. 28. If electric fluid be communicated to an insulated metallic body, suppose a sphere, it will be diffused over the surface of the sphere, and the central parts will be void of electricity. This is satisfactorily proved by the experiments of M. *Columb*, M. *Biot*, and others.

Exp. First, let the metallic sphere and the air be in a state of equilibrium, and now imagine, for a moment, that the metal is removed, or annihilated, so that the space it occupied becomes a void, the surrounding air, being supposed to be sustained in its first state, and place: and further, suppose that electric fluid is communicated to the void space, it will be diffused through that space by the mutual repulsion between its atoms, and those which reach the surface of the surrounding air will be attached to the atoms of the air, this will remove a portion of pressure from the internal fluid, and an additional quantity will be attached to the air, and hence, the pressure being thus removed, they will at length be so attenuated, that their centers will no longer be found within each other's spherules. Thus the communicated electric fluid will be chiefly attached to the atoms of air forming the surface. Again, let the metallic sphere be in its place and state of

equilibrium, and the electric fluid now communicated to it, suppose to its internal parts, it will be diffused as in the case of a vacuum, because the metal is a good conductor, and indeed now, it will more readily be diffused, because the atmospherules of ethereal matter, attached to the atoms of the metal, oppose the union of the electric fluid with the metal, and this circumstance will accelerate the dispersion, and the electric matter will therefore be applied to the particles of air which adhere to, and are in contact with the metal, that is, nearly the whole of the communicated electric fluid will be diffused over the surface of the metal, and the central parts will be unelectrified.

PH. 29. Similar insulated conductors, equal in magnitude, and charged with electric fluid to the same degree of intensity, contain the same quantity of the fluid, whether they are solid or hollow.

Exp. This follows from the last; for since the surfaces are equal and alike, and the air the same at both surfaces, and also that the electric fluid is retained at the surfaces by the surrounding air, it will follow, that both will contain the same quantity of electric fluid.

PH. 30. The same things supposed, if the bodies are in a negative state to the same degree of intensity, they will be equally deficient, whether they are solid or hollow.

Exp. For supposing equal quantities of electric fluid taken from both, then since the state and quantity of the air is the same at both surfaces, the equilibrium is equally destroyed, and the intensity is the same; hence conversely, if the intensity is the same, the deficiencies of the electric fluid are equal.

PH. 31. If an insulated solid metallic ball be electrified, and if a thin hollow sphere of metal, equal in surface, be

also insulated, and brought into contact with the other, it will receive just half its superabundant fluid.

Exp. The balls being equally good conductors, and in contact, it appears by the two last phenomena that they will contain equal quantities of the fluid, or will be equally deficient, hence half the excess of fluid will pass from the first to the other.

Ph. 32. If the balls be unequal, the smaller one will receive more of the fluid than the quantity answering to the ratio of its magnitude. Thus M. *Columb* found, that when the one ball was fifteen times less than the other, it contained but eleven times less fluid.

Exp. When the balls are in contact, the smaller one forms a prominent part on the other, and hence (*prop*. 17, and *cors. sect*. ii.) the ethereal matter will be most protruded on it, and hence it will contain a greater proportionate part. For the same reason it is found that there is an increase of electricity on the projecting parts of electrified bodies. When the balls are negative the same holds good, because in this case, the relations of the forces are the same, but in contrary directions.

Ph. 33. If an electrified insulated body be connected with the earth by a good conductor, it is speedily restored to its natural state, if it be a good conductor, but not so if it be a non-conductor.

Exp. The reason of this will be seen at once from a consideration of *phenomena* 6 and 20; which also will appear from several others.

Ph. 34. If two wires, one short and of small diameter, the other long and thick, be employed as conductors; the short and thin wire will transmit a greater portion of the fluid than the thick one, other circumstances being the same.

Exp. The shorter passage in the small wire affords one reason, it also follows from this, that in the small wire the fluid proceeds in one body, or in a condensed state, while in the thick wire, it is more diffused on the surface, hence, because of its less intensity, it is more resisted by the air, and also on account of the greater quantity of air to which it is exposed in its passage.

Ph. 35. A large quantity of electricity will pass through a good conductor of a very great length in an imperceptible portion of time, but a small quantity takes a longer time.

Exp. All bodies in some degree resist the passage of electric fluid of low intensity, as before shewn, and this accounts for the fact.

Ph. 36. When a conductor is electrified in a very high degree, a considerable portion of the electricity escapes from its surface.

Exp. For no bodies are perfect non-conductors, and they are the less perfect, as the intensity is greater; hence the air will be a partial conductor, when the body is highly electrified, and hence much fluid will be carried from the electrified body.

Ph. 37. When the conductor is electrified in a less degree; if it have long small projecting parts, the fluid will escape at those parts.

Exp. For the small projecting parts will be most charged with the fluid, or most deprived of it, (*prop.* 17, *sect.* ii. and *ph.* 32), and hence by the last, it tends to escape, or if negative to be received at the projecting parts.

Ph. 38. Fine pointed conducting bodies, as metallic wires, projecting to some distance from electrified bodies, or presented towards them at a small distance, readily throw off, or receive the electric fluid, and tend to reduce the body to its natural state.

Exp. This will follow as a natural consequence from *phenomena* 34 and 37, and from *proposition* 17 and its *cors.*; for the resistance to the fluid is taken away from the points by the diffusion, intermixture, and motion of much ethereal matter or electric fluid at those points.

Excitation of Bodies.

Ph. 39. When two dissimilar bodies, especially non-conductors, are rubbed together, electrical signs generally appear, one of the bodies being positive and the other negative, and the excitation is in most cases greater, when the bodies are more unlike in their nature.

Exp. The first part of this was explained in *ph.* 2, and it is evidently to be expected on account of the different degrees of hardness, texture, roughness of surface, and other differences, so that when such bodies are rubbed against each other, the electric fluid on the surface of one will pass over to the other, and the more so as they are the more unlike; this transit of the fluid therefore takes place, when the bodies come into close contact, and separate again, in the act of mutual friction.

Obs. The most general way of exciting common electricity, is by means of an electrical machine. There are various sorts and constructions of this instrument, as may be seen in Treatises on Electricity. The most simple and complete machine consists of a glass cylinder, from 8 to 16 inches in diameter, and from 12 to 24 inches long,

turning by means of a wince, or otherwise, between two upright pillars, fixed on a strong mahogany base. To one side of the cylinder is applied a cushion, formed of leather stuffed with horse hair, or wool, &c. about two inches shorter than the cylinder, and nearly two inches wide; it is attached to a piece of wood, and supported by a strong glass pillar, and may be made to press with any moderate force against the cylinder, by means of a spring. To the cushion a cylindrical conductor may be attached when required. Before the opposite side of the glass cylinder, another insulated conductor is placed called the prime conductor, which is furnished with a row of pointed wires, the distance between the extreme points being about one inch less than the length of the cushion: the points are called collectors, and are to be placed so that the line joining their extremities may be parallel to the axis of the glass cylinder, and at half an inch distance, or less, from its surface.

To the cushion is applied an amalgam, made by melting together one part by weight of tin, and two of zinc, and pouring the melted mass on four parts of mercury, in a wooden box, or iron mortar, and afterwards triturating the compound. Also from the top of the cushion proceeds a silk flap, reaching over the glass to within about one inch of the collectors.

Ph. 40. The electrical machine and apparatus being dry and in proper order, and the conductors being removed, on turning the machine the cylinder is electrified positively, and streams of light will appear to pass on the cylinder from the silk flap to the opposite side of the cushion. On presenting the knuckle, there will be perceived a hissing noise, and sensible wind, with luminous radiations.

Exp. The glass is strongly excited by the rubber, and rendered positive, while the rubber is left in a negative

state (*ph.* 3); the excited electric fluid being in abun dance, after leaving the silk flap, darts forward in collected masses to the negative rubber, (*ph.* 36), because the centers of its atoms are forced far within each other's spherules. When the hand is presented, the fluid flies towards it, the resistance being lessened in that direction, as will be shewn in several of the following phenomena.

Ph. 41. The same things being supposed, and now the positive conductor with the collectors being placed before the cylinder, and a chain or wire hung from the cushion, connecting it with the earth, through the medium of the table, floor, &c., the machine being turned, the prime conductor acquires the positive electricity, and it will be found, that, if an uninsulated conducting body be presented to the prime conductor, electricity will be conveyed rapidly along that conducting body.

Exp. The glass cylinder, while passing the cushion in close contact, receives from it a considerable portion of electric fluid, because its atoms attach themselves more strongly to the glass than to the amalgam, (*ph.* 2 and 3); hence the glass leaving the cushion, has obtained and carries off an accumulation of the fluid; the loss sustained by the cushion is supplied to it immediately, because of its connection with the earth (*ph.* 6, and 20), and hence it is again in a state fit to supply the successive parts of the glass cylinder as it revolves. Now the pointed collectors readily receive the fluid from the charged revolving surface, (*ph.* 37 and 38), and the glass thus deprived of its surcharge, again receives a new stock, when it comes in contact with the cushion, and hence a continual current of electric fluid is thus drawn from the earth through the chain to the cushion, and thence conveyed to the earth again through the conducting body, presented to the prime conductor.

Ph. 42. If the cylinder of the machine were made of glass rendered rough on its surface, and a smooth rubber applied, it would on turning the machine become negatively electrical, and still strong electricity would pass along the conducting bodies, which respectively connect the prime conductor, and the cushion, with the earth.

Exp. A large quantity of electric fluid, naturally belongs to the glass, because it is found strongly to adhere to it, and this will be most dense at the extremities and points produced in making the glass rough, and will more easily leave these points, than the smooth surface, hence the smooth rubber without difficulty takes, or wipes off, the electric atoms from the prominences (see *ph.* 37, 38, and 39, and also *ph.* 2, and 4), hence the glass becomes negative, and is now supplied from the earth by the conducting body, through the prime conductor and the pointed wires, which deliver the fluid to the deficient glass cylinder, and the redundancy of fluid delivered to the rubber is also discharged by means of its connection with the earth, hence a current is produced, as in the last phenomenon, but in the contrary direction.

A cylinder made of sealing wax, or of some resinous substance, would have the same effect as the rough glass.

Sch. It may be observed, that by means of a machine, a current of electric fluid is put into circulation from the earth to the earth again, in the case of a positive cylinder as in *phenomenon* 41, the current passes from the earth to the cushion, applies to the cylinder, and is taken by the collectors, and conveyed to the earth again through the prime conductor, and the conducting body applied to it for that purpose. In the case of *phenomenon* 42, there is the same line of motion, but the direction of the current is in the opposite way.

The negative and positive state of a body may be known by means of electrical attraction to be explained in its order; but, on account of the great variety in the nature, composition, and other circumstances of bodies, it will not be easy in general to foretel which of the two bodies, submitted to mutual friction, will be positive or negative. The following phenomena relating to excitation by friction will assist in judging on various occasions. Non-conductors being most susceptible of excitation have been called electrics, and conductors are said to be non-electrics, because they cannot be excited except when insulated.

PH. 43. When two electric bodies are rubbed together, in most cases that whose surface is the most set with asperitics, points, and fibres, gives the positive state to the other, and is itself negative.—Thus smooth glass is positive, and rough glass is negative, when rubbed with silk, and thus baked smooth wood is negative, when rubbed with a smooth rubber, but positive when rubbed with coarse flannel.

Exp. This is a more general case, but is explained as *ph* 3, 4, 41, and 42, the body, most attractive of the fluid, being positive when smooth, and negative when it contains many asperities.

PH. 44. If not counterbalanced by other circumstances the harder of the two bodies generally becomes positive, and the softer one negative.

Exp. This doubtless arises from the yielding nature of the softer body, since, from that circumstance, the electric fluid will, on pressure during friction, become more dense at the surface, will vibrate, and will therefore be given out with greater facility to the other body.

PH. 45. Solids whose parts yield on pressure, and are strong electrics, such as resinous bodies, are in most cases negative, when rubbed with other bodies.

Exp. This will follow for the same reason as stated in the last, since, in this instance especially, large quantities of the electric fluid will be brought to the surface of the body, and will necessarily apply to the rubber while in contact.

Ph. 46. Slight differences in the circumstances will determine the one or the other body to become positive or negative.

Exp. The fluid on both bodies being at first in a state of equilibrium, and held in a condensed state by the atoms of the electric, a small disturbance will dispose the body to emit a part of its fluid, or to receive more, and hence the fluid will be determined to the one or the other body as small differences in the circumstances may determine.

Ph. 47. Almost all electrics may be made to acquire the one or the other power, by using a proper rubber.

Exp. This follows from the preceding explanations.

Ph. 48. The same electric, rubbed with the same rubber, exhibits at one time the negative, and at another time the positive state, either from a slight alteration in the surface, or difference of applying the rubber, or in the temperature and dryness of the air, &c.

Exp. All this is a natural consequence of what has been explained, (see *ph.* 46).

Ph. 49. The excitation is produced by friction in carbonic acid, hydrogen, and other gases, as in common air, with some inconsiderable differences.

Exp. The same reasons apply here as in the cases above, the circumstances in other respects being the same and these gases being, like common air, non-conductors.

Ph. 50. If a pane of glass be broken, the two pieces at the fracture will frequently be in opposite electrical states.

Exp. Since slight causes will dispose the one or the

other to part with its fluid, (*ph.* 46), it may easily happen in many cases, from the inequality in the surface, and from the form of the fracture, that the one side will receive more than its own share of the fluid, which is ready to flow over the fractured parts, and it will therefore be positive, and consequently the other becomes negative.

Ph. 51. The same will happen when a stick of sealing wax, or other electric, is broken.

Exp. This arises from the same cause; when they are broken, the edges and corners of the fracture are generally more prominent in the one than in the other; and both in this, and the last, the state of the vibrations of the ethereal matter at the moment of fracture will produce some difference.

Ph. 52. Dry air or other gases, blown on glass by a pair of bellows, renders the glass positive, and the air negative.

Exp. Since glass is a better non-conductor than air, the electric fluid more readily adheres to its atoms, and when the air is blown on it, strongly, it will as in the case of friction yield a portion of fluid to the glass.

Ph. 53. Melted sulphur, poured into a metal vessel, becomes positive, and the metal negative; but the reverse sometimes happens, and the effects are different, when it is poured on different substances.

Exp. Whether a body will become positive or negative, depends on circumstances, which are not always easily observed, as shewn in some of the foregoing instances, hence there is no discordance between our theory and these facts.

Ph. 54. Electricity is developed by heat, and by evaporation, and chemical changes.

Exp. This is nothing more than an immediate deduction from the theory, and several of the foregoing phe-

nomena, and is what evidently ought to be expected to result from these processes and changes.

Ph. 55. The tourmaline, and other crystals, whose form is not symmetrical, give signs of electricity by heat alone. One end becomes positive, the other negative, and the middle neutral, in the direction of the strata.

Exp. Heat may be easily conceived to disturb the atmospherules of the particles of the crystals, and from the crystalline arrangement, and the want of symmetry, which affects the several parts of the crystal, the action of the caloric may cause the electric fluid to occupy one side of the molecules rather than the other, and hence on the whole to render one end positive, and consequently the other negative, which state is retained some time, because of the non-conducting property of the crystal.

Ph. 56. The tourmaline, and crystals which are rendered electrical by heat alone, are found to be positive at that end which presents the greatest number of facets, and consequently of angular edges and points.

Exp. This circumstance agrees perfectly with our theory; for according to *prop.* 17, and its *cors.* the ethereal matter, and consequently the electric fluid, will be propelled or extended, by a proper degree of heat, most towards that end where there are the most edges, and angular points; hence the caloric, pressing on the electric fluid, will produce this effect, that is, the electric fluid will tend to escape at the one end and consequently to enter at the other, making the most angular end positive, and the opposite negative, while the middle is consequently neutral.

Ph. 57. When the heat is considerably increased, the crystal ceases to be electrical.

Exp. For the accumulated caloric itself, with some electric fluid will now more rapidly escape at the angular

points, and in escaping will re-act continually on the electrical part of the atmospherule (*prop.* 14, *cor.* 9, 10, and 11. *sect.* ii.) repelling them in the opposite direction, hence the electrical equilibrium will be restored, and the electrical signs will disappear.

Ph. 58. When the temperature of the crystal is raised still higher, the electrical signs appear in a reverse order, *viz.* the end having the fewest facets is positive.

Exp. The caloric escapes now in greater quantity, and with greater force than as stated in the last; and hence the repulsion or re-action, which necessarily takes place between the caloric which escapes, and the atoms of the electric fluid (*prop.* 14, *cor.* 9, 10, and 11. *sect.* ii.) is sufficient to cause the electrical part of the atmospherules of the atoms of the crystal to extend in the opposite direction; that is, the electrical state of the two ends is reversed, as the crystal cools it passes through the different gradations to its original state, which confirms this explanation.

Ph. 59. In the crystal called borate of magnesia, whose form is generally that of a cube, incomplete on its edges, and farther modified by facets, at half of the solid angles alternately placed, the four axes, meeting the opposite angles, find a facet at one extremity, and not at the other, the four extremities where the facets are, become positive, and the other ends or corners are negative.

Exp. This is exactly agreeable to the case of *ph.* 56, and requires no farther elucidation.

Ph. 60. If two polished plates of different sorts of metal, about 4 or 5 inches in diameter, be placed on each other by means of insulating handles, and after a while removed, the metal, which has the greatest affinity for oxygen, is found to be positive, and the other negative.

Exp. Atoms of air, and consequently of oxygen adhere

to the surfaces of metals, and other bodies, more or less closely according to circumstances, (see *sect.* ii, and vi.) Now the metal which has the greatest affinity for oxygen, will, while they are in contact, cause some of the atoms of oxygen to approach it from the other plate, to which the adhesion is feeble. Hence a portion of the electric fluid will pass with it to this metal, rendering it positive, while it leaves the other negative, and although it is not necessary that combination should take place, yet the effect will be greater or less, according to their different facilities of combining with oxygen, modified perhaps by other circumstances.

Excitement by Induction.

PH. 61. When a body is rendered electrical, the contiguous air is electrified by it to some considerable distance, greater or less, according to the intensity of the action.

Exp. If the body be positive, the accumulated atmospherules of the atoms of that body will cause the atmospherules of the contiguous air to extend outward, or from the body, (*prop.* 27, *sect.* ii.); hence the atoms of the air will be in a state fit to receive the electric fluid on the sides facing the electrical body. If the body be negative the reverse takes place, (*prop.* 28, *sect.* ii). When the intensity of the electricity on the electrified body is great, a portion of the fluid will pass from it, when it is positive, to the contiguous air, (*ph.* 6, and 36); since the air is in this case a partial conductor, and hence the neighbouring air will become positively electrified. But if the elec-

points, and ir ... gative the contiguous air will electrical par ... fluid, and will thus itself become and 11. sec

hence the ... insulated conductor be placed at a small electric ... electrified body, so as not to receive a

PH. ... the two extremities of the conductor will be still ... contrary electrical states; the most distant end of the viz. ... approximated body will be in the same state as that of the body by which it is affected, and the nearer end will be electrified with the contrary power.

V ... *Exp.* Let the conductor A, *fig.* 50, be electrified so as to be in the positive state, and let another conductor, BC, properly insulated, be placed near it, and at such a distance as not to receive a spark. Then, since A is positive, the atmospherules of the atoms of air around it will be extended outward, as in the direction of the short lines, attached to the circles representing the atoms of air, (*prop.* 27, and *ph.* 61). Again, since BC is a conductor, the electric fluid moves much more easily along its surface, than through the air, hence the extended atmospherules of the air contiguous to B, will find less resistance towards B than towards other parts in the air, hence the direction of the atmospherules of the air surrounding B, at a little distance from the end, will be changed, and turned towards the conductor B, as shewn by the little arrows, and this will still further tend to protrude the electric fluid from the end B, towards C, till the equilibrium is attained. It is evident that from this effect, the atmospherules of the air near C will extend outward, as before they did at A. Thus the end B of the conductor BC, will be in a condition fit for receiving electric fluid from any other conductor in its natural state, and the end C, for giving out a portion to such a conductor; that is, the end B is negative and C is positive. If A had been negative, the direction

of the atmospherules of the air would have been reversed, and it is seen at a glance that C would have become negative and B positive. This is called induced electricity, and BC is said to be electrified by induction.

Ph. 63. If the neighbouring conductor BC, *fig.* 50, have its extremity connected with the earth by a conductor, it acquires an electrical state opposite to that of the body A; and the more so, if instead of the earth, it be connected with a conducting body in a state contrary to that in which A is electrified.

Exp. Suppose BC connected with the earth, by a wire or chain, as FG is at G, it is manifest that the fluid propelled from B towards C, as shewn in the last explanation, will now readily pass along the chain to the earth, and BC will be negative throughout its whole length, if A be positive, and the contrary if A be negative. If C had been connected with a body in the contrary state to that of A, these effects would manifestly have been increased.

Ph. 64. If there be a series of insulated conductors, near each other in a line but not in contact, and the farther extremity of the last of the series communicating with the earth, as BC, DE, and FG, then each of the intermediate insulated bodies will be electrified at the end directed towards the electrified body A, with the contrary power, and at the opposite end with the same power as that of A.

Exp. The effect of A on B will be as shewn in *ph.* 62, but in a much greater degree, because the resistance is partly removed by the conveyance of a portion of electric fluid to the earth by the chain H, (*ph.* 63), and since the end C is thus rendered electrical, and in the same state as A, DE will be electrified by C, as BC is by A, and likewise FG will be electrified by the end E, so as to be in a

trified body be intensely negative the contiguous air will yield to it a portion of fluid, and will thus itself become negative.

Ph. 62. If an insulated conductor be placed at a small distance from an electrified body, so as not to receive a spark from it, the two extremities of the conductor will be in contrary electrical states; the most distant end of the approximated body will be in the same state as that of the body by which it is affected, and the nearer end will be electrified with the contrary power.

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state opposite to that of E, or A, (*ph.* 62 and 63), and thus the effect may be propagated through a long series of conductors.

Ph. 65. The intensity of the electricity induced on BC or DE, (*ph.* 62, and 64), decreases from the extremities, and is null somewhere towards the middle.

Exp. This ought to follow from *ph.* 62 and 64; for since the atmospherules of the air are extended in opposite ways at the two ends, in respect of B and C, there is some part between them, where the natural equilibrium must remain, and evidently the intensity of the electrical state will decrease as we recede from either end towards this part.

Ph. 66. The point in BC, which shews no signs of electrical attraction, lies nearer to B, as BC is removed farther from A.

Exp. For the action is more feeble on the fluid at B, as it is more distant, and hence this effect ought to ensue.

Ph. 67. If BC be removed to a considerable distance, it gives no signs of electricity.

Exp. The reason of this is obvious, because the air is insensibly affected at such a distance.

Ph. 68. The insulated conductor BC, being removed in its insulated state, is found to have lost scarcely any thing of its electricity, but remains nearly in its natural state.

Exp. The distance is stated to be such, that the spark does not pass from A to BC, *fig.* 50, and the electrical atmospherules of the air do not commix with the fluid on the surface of BC, (*prop.* 14, *sect.* ii.); and if indeed a small portion of the fluid should pass at one end, nearly an equal quantity would escape at the other, the conditions being much the same; hence all that happens to

BC is merely a disturbance of the fluid, and when removed it will therefore be in its natural state.

Ph. 69. These effects do not take place in the vacuum made by an air pump.

Exp. Here the atoms of air are wanting by means of which the effect in the former cases was produced, and hence the electrical signs are in this instance wanting. This is agreeable to, and confirms the preceding explanations.

Ph. 70. The electrified body A, being insulated, is affected by the presence of the insulated cylinder BC, so that its electrical intensity, at the parts adjacent to B, is increased, and on the opposite side diminished.

Exp. For the resistance to the extension of the atmospherules of the air from A, when positive, is diminished by the conductor BC, as is evident from *ph.* 62, and 64; also the force favouring the extension towards A, when it is negative, is increased by the presence of BC; hence it follows, that in both cases the intensity of A will be augmented on the side towards B, and consequently diminished on the opposite side.

Ph. 71. If while the insulated conductor BC is near the electrified body A, we touch the end C with another insulated conductor in its natural state, and after the contact remove this conductor still insulated, it will be found electrified in the same state that A is in; and BC being now removed, also without destroying the insulation, it will be found in an opposite state to that of A.

Exp. Since by *ph.* 62, and 64, BC is, at the end C, in the same electrical state as A, it will therefore give a portion of the fluid to the touching conductor, when A is positive, and receive a portion when A is negative, (*ph.* 6); hence that conductor will be found in the same state as A,

and BC in the contrary state, both being removed, while they remain insulated.

Ph. 72. The same things being supposed, except that the end B is now to be touched by the insulated conductor, the reverse will happen, the touching conductor will be in the contrary state to that of A, and BC will now be in the same state.

Exp. The reason of this is evident from the last, being simply the reverse: for the end now touched is in the opposite state.

Ph. 73. If the extremity C of BC be touched for a short time by an uninsulated conductor, and afterwards BC be removed from the influence of A, remaining still insulated, it will be found in the contrary state to that of A, in a still greater degree than in the case of *ph.* 71. If the end B had been touched instead of C, BC would have been electrified strongly in the same state as A.

Exp. In this case there is an uninterrupted, free passage from the earth, for the fluid to enter BC at the end which is in a proper condition to receive it, that is, where it is negative, or to escape from it at the other end, where it is positive, which clearly accounts for the fact.

Production of the Spark.

Ph. 74. Things being as in *ph.* 63, if BC, now connected with the earth, be gently moved towards A, when it arrives at a certain distance, greater or less according to the intensity of A, a luminous spark will be seen to pass between A and B, attended with a snapping sound: and

if the intensity of A be kept up to the same degree, by fresh communications of the electric fluid, sparks will continue to pass successively between A and B.

Exp. In proportion as BC approaches A, its fluid at B, A being positive, is more and more repressed by the actions of the atmospherules of the contiguous air, hence B becomes more powerfully negative, (*ph.*62 and 63), and A is more intensely positive, (*ph.* 70); consequently, the atmospherules are more extended from A towards B, so that the fluid accumulates more abundantly on A, at the side towards B, and presses towards a line joining them, till at a certain term, of the intensity and distance, it becomes sufficiently powerful to pass off from A in that line, in a mass, through the air to B. Some idea of the disposition of the atmospherules of the air, and the line of motion of the spark, may be formed by noticing *fig.* 65, the atmospherules of the air being directed obliquely towards the dotted line, inclining from A to B, will resist the dissipation of the fluid on each side, hence it must take its direction in that line, rather than in any other. If A had been negative, the atmospherules would still have been inclined towards the same line, but in this case from B to the side A. The body of fluid or spark in its progress between A and B necessarily displaces the air in the line of its motion, which immediately rushing into its place again produces the sound; and the mutual resistance, between the passing fluid and the air, causes the sudden extrication, and rapid dissipation of abundance of ethereal matter, rendering its path luminous; and, because the conductor BC is not insulated, the spark received by it is immediately conveyed to the earth by the repulsion between its atoms, so that BC is reduced to its previous state, and will receive the spark again if the intensity of A be kept at the same degree.

If we suppose A to be negative, the explanation is precisely similar, only that now the spark passes from B to A, that is, in the opposite direction.

Ph. 75. Things being as in *ph.* 62, and now if BC be gently moved towards A as above; it will in this case also produce a spark at a certain distance, less than as in the last phenomenon, and the insulated conductor BC, having received or given the spark, will be in the same electrical state as that of A, which, its intensity remaining the same, will not now yield a succession of sparks.

Exp. The reason for the spark is the same as in *ph.* 74, but a less distance is necessary because BC on account of being insulated, cannot be so powerfully affected by A at the same distance. Also A being positive when the spark has passed from A to B, BC will be positive through its whole length from a redundancy of fluid, which cannot pass off, since BC is insulated, and hence it cannot take another spark, the intensity of A remaining the same. The same will hold similarly when A is negative, the spark now passing from B to A, and rendering BC negative from its loss of fluid.

Ph. 76. There are various degrees in the force of the spark, from that of a very powerful one, to that which is almost imperceptible, and even down to the silent flowing over of the detached electric fluid, since in some circumstances the adjacent body on being removed is found to have become in some degree electrical without the passage of a sensible spark.

Exp. The foregoing explanations will be sufficient to shew that this is what ought to occur in all its degrees according to the facts.

Ph. 77. If BC and A, *fig.* 50, be both insulated, as in *ph.* 62, and electrified to the same degree, no spark will pass between them when they are made to approach;

but the one will re-act on the other, so as to diminish the electrical intensity between them.

Exp. For it is evident that the extension of the atmospherules of the air between A and B will be in opposite directions, and this will prevent the spark; and, as appears by *ph.* 62, the action of A will cause the fluid of B to recede towards C: and for the same reason the action of B will cause that of A to recede, till an equilibrium is attained.

Distribution of the Fluid.

PH. 78. If two equal spherical conductors be electrified, and placed in contact, they will have an equal excess or deficiency of the electric fluid, but so disposed, that at the point of contact, and to the distance of about 20° from it, the bodies will have no sensible electricity, and from that point it increases continually to the opposite sides, so that calling the quantity 1 at 90°, we shall have the quantity at 30° equal .2013, at 60° it will be .7994, and at 180° about 1.3576 according to the experiments of M. *Columb.*

Exp. When the balls AB and A*b*, *fig.* 56, are in contact at A, they, being conductors equal and similar, will obtain or lose equal quantities of the electric fluid, (*ph.* 29, 30, and 31). Now the electricity will produce equal and opposite actions on the air around the point of contact, tending to propel the electric fluid over the surfaces of the balls, towards B and *b*, (*ph.* 28, 62, and 77), if the bodies be positive, or to direct the fluid towards A if they be

negative. And thus the electrical signs will disappear at, and to some distance from the place of contact, and its intensity will increase from thence to the opposite sides at B and C, where it will be greatest.

Ph. 79. If the spheres are unequal as in *fig.* 57, the less will contain the larger proportion of the electricity, in comparison of its surface, but it will be more unequally distributed, being insensible to a greater distance, while on the larger ball, it is insensible to a less distance, than that of *ph.* 78, above noticed, and more equally distributed.

Exp. The less ball contains a larger proportion, in excess or defect, of the fluid by *ph.* 32, but a less absolute quantity; and evidently the larger surface A*m* will produce a greater effect on A*n* as it becomes smaller, and A*n* a less effect on A*m*; hence the phenomena here mentioned must evidently take place.

Ph. 80. If the balls be equal, and after being in contact be gradually removed, the distribution of the fluid becomes more and more uniform; but still they are less dense at the sides facing each other than at the opposite sides, till they are beyond each other's influence.

Exp. This is a necessary consequence of what has been already advanced on this subject in *ph.* 62, 63, and in several of those which respect the excitation of bodies.

Ph. 81. If the balls AB and A*b*, *fig.* 58, be unequal and removed from the contact, the less ball while very near is in the opposite electrical state, at the point which was removed from contact, at a certain distance it is not sensibly electrified, and at a still greater distance, it is in the same state as that of the balls at first: thus, if the diameter of the greater ball be 11 inches, and that of the less 8 inches, the point *a* is in a state contrary to that of A, at less than the distance of an inch where it is neutral,

and, when separated more than an inch, *a* is electrified in the same state as A.

Exp. When the balls are equal their actions nearly neutralize each other, at A and *a*, the distance being very small, hence when one is less than the other, the effect ought to be increased, (*ph.* 79), and hence some portion even of the natural quantity of fluid will be propelled from *a* towards *b*, when they are positive, and the contrary when they are negative, (*ph.* 62); but this effect will decrease with the distance, hence, at a certain point, *a* will be in its natural state, and, at a greater distance, in the same state as A in all its parts.

Ph. 82. Things being as in the last, the larger ball at the several distances will be, in all its parts, in the same electrical state as at first, and the distribution of its fluid will be more uniform than in the case of the two equal balls.

Exp. There can be no difficulty in this when the preceding phenomena are considered. The effect of the small ball is not sufficient to alter the electrical state of the larger.

Ph. 83. If a non-conductor as DE, *fig.* 50, be presented to an electrified body, so as to receive a portion of electricity, suppose at D, it will often be found to be electrified positively and negatively in alternate zones.

Exp. This will arise from the difference in the conducting power of the body and the air, in connection with the variable intensity of the body C, by which it is electrified. Thus let DE transmit electricity as far as to *a*, and the air as far as to *b*, (suppose it is positive), then, the atmospherules of both will be extended towards E; now let the intensity of the electrifying body C be diminished, the atmospherules will recede towards D, and the air will begin to deposit a portion of its superabundant fluid be-

tween *a* and *b*, electrifying a zone near *b*. Again, let the intensity of C be increased, and DE will not now as before be equally electrified as far as to *a*, because of the electrified zone *b*, but the air will be electrified to a greater distance as suppose to *c*, because the zone *b* conspires with the actions of C. The intensity of C being again reduced, another zone near *c* will become electrical, and thus may several alternate zones be affected, diminishing in intensity as they recede from D. Similar reasoning will evidently apply when C is negative.

Attraction and Repulsion.

PH. 84. Two bodies electrified, both positively or both negatively, will repel each other.

Exp. Let A and B, *fig.* 59, be two very light insulated balls, both positive: then the action of the electric fluid of the ball A, on the contiguous air, will be such as to extend its atmospherules outward, (*prop.* 27. *sect.* ii), as shewn on an atom of the contiguous air by the short line *a*, the effect of B on the same atom would be such as to extend the atmospherule, as shewn by the short line *b*, hence the compound effect will be in a line between these directions *a* and *b*, proceeding from some point as *m* between the centers A and B, this direction is denoted by the dart *c*. In like manner the actions of A and B, on an atom of the air on the other side, would be in the directions *a'*, *b'*, and their compound effect would consequently direct the atmospherule towards *c'* from some point *n* also between A and B. Hence the compound actions of A and B on

all the atoms of air in the vicinity of A, on every side of it, would be to protrude all their atmospherules from points situated in AB, between the centers A and B; the same reasoning applies equally to the joint actions of the balls A and B on the air contiguous to B. Therefore it is evident, that the sum of all the forces is a force tending to direct the atmospherules of the air in opposite directions in the middle between the centers, and at right angles to the line joining them, as shewn at PQ, and in every way from that line, as from the center of a circle, in all directions of the radii. This position of the atmospherules being produced by the actions of the forces on both sides, it is evident, that the compound force with the re-action, operates on both the balls through the medium of the air, from a plane passing through PQ at right angles to AB, and between the centers A and B, that is, the balls are repelled, and if sufficiently light will recede.

Next let the bodies be both negative as A and B, *fig.* 60: here, by observing the directions of the arrows, and recollecting the above reasoning, it will be seen, that equally in this case as in the preceding, the atmospherules of the air, in the neighbourhood of both bodies, are directed *towards* points in AB, between the centers A and B, as when both being positive, they were directed *from* such points, and the force producing this effect with its re-action will now also be directed both ways, from a plane passing at right angles through PQ, acting on the balls through the medium of the intervening air; hence the repulsion will take place equally as before, and for reasons equally plain and evident. If any electric fluid pass from atom to atom, it must be between the bodies where the combined forces are greatest, and this when it occurs will augment the repulsion in both cases.

being diffused over the surface of the larger one becomes nearly insensible.

Ph. 93. If while the ball is electrified the excited body by which it was electrified, be made slowly to approach it, we shall find it will constantly be repelled: but if a body, of equal intensity, in the opposite electrical state, be presented, it will be strongly attracted.

Exp. This is only a particular case of *ph.* 84 and 85: the repulsion takes place in the first instance, because the ball and body are in the same state, and the attraction in the second case, because they are in contrary states. The body presented appears immoveable, because of its weight, the other therefore seems to be attracted or repelled by its action.

Ph. 94. That the repulsion is mutual will appear by attaching two pith balls to a linen thread and fastening them to a non-conducting support, electrify the balls as before, and they recede from each other.

Exp. This is evidently what ought to take place by *ph.* 84, which shews that the repulsion ought to be mutual as the experiment evinces.

Obs. Various instruments have been contrived, depending on these principles; they are called electrometers or electroscopes, and are employed to indicate the intensity, and the kind of electricity of an electrified body: a pair of pith balls suspended by linen or silk threads, as occasion may require, is the most simple instrument of this kind.

By means of an insulated ball, such as is represented in *fig.* 52, we may discover the kind of electricity of any electrical body; for the body is in the same state as the ball, if by moving it slowly towards the ball there is a repulsion, but if attraction immediately appear, it is in the contrary state.

Ph. 95. If the suspended ball (*fig.* 52) be feebly electrified, and another larger body be strongly electrified, and made to approach very near it, the ball will be attracted instead of being repelled, as in *ph.* 93, the body excited with the like power was repelled.

Exp. The very great electric power of the body, in comparison of that of the ball, is sufficient to cause the fluid of the ball to recede to the opposite side, as in *ph.* 62, and hence they are in opposite states, and by *ph.* 85, they must attract each other.

Ph. 96. The electrical attractions and repulsions are propagated through plates of glass or sealing-wax, or other electrics. Thus an excited piece of sealing-wax suspended in a phial, will attract or repel light bodies on the outside.

Exp. This will occur, because the extended atmospherules of the atoms of the adjoining air, will affect similarly those of the glass, and these will in like manner act on the air without; *fig.* 62 will give some idea of this, a section of the glass being shewn, and two of its atoms, with one of air on each side; the short lines are to shew the side to which the atmospherules extend. Thus if the atmospherule of the atom of air *a* be extended towards the glass, those of the glass *b* and *c*, with that of the air on the opposite side *d*, will be disposed according to the same direction, and the converse when *a* is opposed to a negative body.

Ph. 97. If a metallic plate be placed horizontally as *ab*, *fig.* 55, and not insulated, and another plate *cd*, be suspended above at some distance and parallel to it, and if the upper plate be electrified, light bodies, such as bits of paper cut into triangular forms, or other figures, will be alternately attracted and repelled, and sometimes will remain suspended for some time in the air between the plates.

Exp. The light bodies will be attracted by the upper plate, as shewn *ph.* 85; when they reach that plate, they will be electrified with the same power, and therefore will then be repelled (*ph.* 6 and 84). Again, when the bodies have angular points they readily receive or transmit the electric fluid, and hence are often repelled in this case before they reach the upper plate, and seem to dance on the lower one. Lastly, the weight of the body, its angular points, and the intensity of the electricity, may be such that they shall receive the electricity from one plate and deliver it to the other at the points, so as to be suspended between them, being repelled or attracted by a small alteration of distance. The repulsion between the body and the fluid entering on one side, and escaping on the other, will frequently cause the angular body to be suspended between the plates.

Ph. 98. If a number of small pith balls be placed on an uninsulated metallic plate, and an electrified glass tumbler be inverted over them, they will dance for some time, flying to the glass and plate alternately.

Exp. The glass will attract them (*ph.* 85), it will then electrify and repel them (*ph.* 6 and 84); but the glass will lose its electricity only near the place where the ball touches it (*ph.* 6), therefore the dancing of the balls will be continued for some time.

Ph. 99. If there be two equal insulated bodies, one a non-conductor, and the other a conductor, each in its natural state, either will be attracted by an excited body, but the conductor will be much more rapidly attracted, and then immediately repelled, the other will be more slowly attracted aud adhere to the excited body, and will generally after some time be repelled.

Exp. This will be at once evident from the above explanations, for the different electrical states, on the sides

of the conductor, are immediately produced by the influence of the excited body on the surrounding air, (*ph.* 62, and following,) it is therefore at once attracted, and having attained the contact is immediately electrified with the same power, and therefore repelled.—But the action of the surrounding air, in order to produce a sufficient difference of the electrical state on the non-conductor, will require some time, because of its non-conducting power, that is, because of the adhesion of the fluid on the atoms of the electric.—Also when this is effected and it is attracted to the excited body, it will adhere to it some time, because it can receive the electric fluid but slowly.

Ph. 100. When a light electric, suppose a feather, has been attracted by an excited tube, and again repelled by it into the air, it may be made to move in any direction by properly presenting the excited tube near it, also the side of the feather which was in contact with the tube, at the time it was repelled, will always be turned so as to face the excited tube when it is presented.

Exp. The first part is evident, for being in the same state, the bodies repel each other; the second part will appear thus, when the feather adhered to the tube (*ph.* 99.) the side first and most electrified was first repelled (*ph.* 84), hence by means of the tube, and the contiguous air, the most distant part, when it leaves the tube, is most electrified, and therefore will be the most powerfully repelled, and this condition will be supported and continued by the action of the air under the influence of the excited body, combined with the non-conducting property of the feather.

Ph. 101. Let *a* and *b* be two bells, connected with an electrified body, and *cd* one connected with the ground, *e* and *f* insulated metal balls at the middle, and free to move; then *e* and *f* will *first* move slowly to *cd*, *fig.* 51,

and afterwards will be rapidly carried backward and forward between the bells, causing them to ring.

Exp. From the foregoing explanations it appears, that *e* and *f* will be attracted both by *a* and *b*; hence *e* will be attracted to *a*, and *f* to *b* only by the difference of these attractions. Again, *cd* is electrified with the contrary power to that of *a* and *b*, because it is connected with the ground, hence it will attract *e* and *f*, and still the more because these have the same kind of electricity as *a* and *b*, on the sides towards *c* and *d*, which is caused both by the influence of these bodies, and of *cd*, hence the reason, why the balls move according to the order above stated, requires no further elucidation.

Ph. 102. The electrical attractions and repulsions of spherical bodies, which are conductors, are inversely as the square of the distance. This has been shewn by M. *Columb* and others.

Exp. Conceive the air, in which the electrified sphere is placed, to be divided into equally thin spherical laminæ concentric with the electrified body. The number of atoms of air in each will be as the surface, that is, as the square of its distance from the center. Again let a given quantity of electric fluid be communicated to the ball, and it will be uniformly diffused over its surface (*ph.* 28), therefore its quantity at each point of the surface, and consequently its intensity, will be inversely as the surface, or inversely as the square of the distance. Now the immediate action of this given quantity of fluid is exercised on the first or contiguous spherical lamina of the air, the first lamina extends the action to the second, the second to the third, &c., but the diminishing force or resistance to the actions at each spherical lamina arises from the air, and will be as the number of its atoms, the density and other things being the same, and the number of these

atoms in the lamina, is as the square of the distance; therefore the forces ought to be diminished as the square of the distance, that is, the atmospherules of the atoms of the air are affected by the electrical body according to this law; the same evidently holds when the ball is negative, but the repulsions and attractions are produced by the actions of the contiguous air, (*ph.* 84, 85, and 86), therefore the spherical conductors approach or recede by forces which are inversely as the squares of the distances, or according to common language, the electrical attractions and repulsions thus vary.

PH. 103. In irregular, especially angular bodies, this law is greatly modified.

Exp. This must follow from the unequal distribution of the fluid on such bodies, and its more or less rapid escape at the angular points.

Accumulation of the Fluid.

Obs. Let a smooth metallic plate, *ab*, *fig.* 55, be insulated on a stand, so that at pleasure it may be connected by a conductor with the earth. Let another similar plate *cd* be prepared, and furnished with a glass handle to insulate it, and to suspend or place it over *ab*; various other conductors may be employed. A pair of pith balls *n m* also may be connected with either plate or a pair with each.

PH. 104. Let *ab*, *fig.* 55, be insulated and electrified, *m n* will diverge (*ph.* 84) by mutual repulsion.

Now let *cd*, not insulated, be placed parallel to *ab* at

some distance, and made gradually to approach it; the divergency of *m n* will continually diminish, as *cd* comes nearer to *ab*, and will cease altogether when it is at the distance of about half an inch.

Exp. Suppose the plate *ab* is positive, *m* and *n* are repelled (*ph.* 84) because they are in the same state, also the atmospherules of the atoms of air near *ab* will be extended on every side outward (*prop.* 27, *sect.* ii. and *ph.* 61), and the most so around its edges (*prop.* 17, and its *cors. sect.* ii). Now when *cd* is placed over the plate *ab* and made to approach it, its natural quantity of fluid is disturbed, and repelled to the side farthest from *ab*, through the medium of the intervening air, (*ph.* 63). Hence the resistance of the air between them, is in part removed from *ab*, and the atmospherules of the air, below *ab*, will be less extended downwards, and more directed towards *cd*, (*ph.* 70). Thus the electrical force is diminished by the presence of *cd* in every direction except towards *cd*, which being in the contrary state removes in part the tension from *ab*; therefore the intensity of *n m* is also diminished, and evidently this effect increases more and more as *cd* approaches *ab*, so as not to receive a spark from it; and thus it is evident, that at a certain small distance, the electrical signs will cease to be exhibited in *ab*, as the experiment shews. Just the reverse takes place when *ab* is negative, and evidently a similar explanation applies.

Ph. 105. Things being as above, if *cd* be gently removed the signs of electricity will re-appear in *ab*, by the divergency of the balls *m n*; and, as *cd* is moved backwards and forwards, *n m* will recede and approach each other alternately.

Exp. According to the last explanation the electric fluid is not carried off from *ab*, but the direction of the

extended atmospherules of the air is merely altered, in consequence of the presence of *cd*, and hence on its removal, the electrical signs are again evinced, and the process is repeated by the alternate movements of the upper plate.

PH. 106. Things being as in *ph.* 104, *viz.* so that *cd* is very near *ab*, but not so near as to receive a spark, and if now *cd* be removed from its situation by an uninsulated handle, having been previously touched by an insulated conductor, it will be found electrified in the contrary state to *ab*, as will be shewn by its pith balls.

Exp. By *ph.* 63 it will appear, that *cd*, while near *ab* and connected with the earth, is in a contrary electrical state to that of *ab*, and being removed by the insulating handle, that state remains, and will be apparent.

PH. 107. When *cd* is removed, as above, it will give or receive an electric spark from an uninsulated conductor brought very close to it, and then if placed in its former situation, and again touched by the conductor and removed, another spark may be obtained, and the same way may be repeated several times.

Exp. The plate when removed is electrified (*ph.* 106), hence the spark will pass between it and a conductor (*ph.* 6, and 74), and it will be again reduced to its natural state, because it is connected with the earth. And since *ab* has not lost its electricity, the same process may be repeated with similar results.

PH. 108. After repeating the process mentioned in the last phenomenon several times, the effect at length becomes insensible.

Exp. This arises from the dissipation of the electric fluid on *ab*, which continually though slowly escapes, in consequence of moisture, dust, &c. in the air, its motion, the edges of the plate, and the slowly conducting power

of the air itself; hence the electrical effects must cease after a greater or less time according to circumstances. If the surrounding medium were a perfectly non-conducting substance, the charged plate *ab* would be a perpetual source of electricity.

Ph. 109. If the two plates be brought so near together, that a spark passes between them, the electricity ceases.

Exp. This follows because one of them is connected with the earth, and since they are conductors, both will be reduced to their natural state.

Ph. 110. If the plates *ab*, *cd*, *fig.* 55, be made large, so as to contain eight or ten square feet each, being formed either of metal or of wood neatly covered with tin foil, or other metallic plate, and also if the lower plate be connected with the earth, and the upper one with the positive conductor of a good electrical machine, and placed in a parallel position, about one inch and a half distant, the negative conductor of the machine not being insulated; then, on turning the machine for some time the apparatus will be strongly charged with electricity, so that a person, touching the conductor which connects the lower plate with the earth, and bringing his other hand into contact with the upper plate, will experience a shock similar to that produced by the Leyden jar.

Exp. This may be understood from *ph.* 104, and those which follow it; the only difference is the greater supply of electric fluid from the machine, and the consequently increased effect.

It may be more fully explained thus; first, suppose the lower plate or board removed, then the upper one being connected with the positive conductor is electrified in the same degree, and the atmospherules of the air are extended from it on all sides, (*prop.* 27, *sect.* ii). Now make the lower board approach gradually to its proper position

and distance, being insulated, and since it is a conductor, its fluid will be repelled to the lower side, (*ph.* 62), and this will give liberty for a farther extension of the atmospherules of the air from the upper board towards the lower, hence it will receive an additional quantity of fluid from the conductor of the machine, that being supposed always to be kept at the same degree of intensity; and this in its turn increases the effect. When the maximum is attained, let a chain or wire be applied to connect the lower board with the earth, and it is evident that the fluid thrown on the under side of the lower board, which is ready to escape, will now pass to the earth; this will therefore lessen still more the resistance to the fluid on the upper board, and hence the electric fluid will much farther and more freely extend downwards, and will receive a fresh supply from the conductor of the machine, acting in its turn as before, till the greatest charge, which the supposed constant power of the machine can give, is effected. From this it must follow, that there will be a great accumulation of the electric fluid on the upper board, and deficiency on the lower one, and if these be now connected by a conductor, a powerful rush of the electric fluid must pass along that connecting conductor from the one to the other, causing a smart shock when this conductor is the human body.

Ph. 111. If the lower board had been connected with the positive conductor, and the upper one with the earth, the effects would have been the same; or if either one had been connected with the negative conductor and the other with the earth, still similar effects would have been produced, the positive conductor in this case not being insulated.

Exp. The first part is a mere change of the arrangement of the boards, and the positions of these will not

affect the results, provided the boards remain still parallel, and at the same distance, other circumstances, except the connection, being alike. The second case produces an extension of the atmospherules of the air from that board, which is connected with the earth, towards the other, and the explanation of *ph.* 110, then applies to this case.

PH. 112. All the preceding effects are produced in a still higher degree, when one of the boards is connected with the positive conductor of the machine, and the other with the negative conductor, both conductors being insulated.

Exp. Suppose that things are as in *ph.* 110, remove the connection of the lower board, and of the negative conductor with the earth; then the negative conductor is deprived of a portion of its fluid by the action of the machine, (*ph.* 40 and 41), and if now the lower board be connected with the negative conductor, it is evident, that the passage of its fluid, tending to escape will be more unrestrained, and free to move towards the negative conductor, than before it was to the earth, since the earth is always in its natural state, hence the effects described in *ph.* 110, will be the same in kind, but augmented in degree.

PH. 113. If the action of the machine be increased, it sometimes happens, that a large spark, or mass of fluid, darts through the air between the boards from the one to the other: and this more frequently occurs when there are protuberances, or uneven parts on either of the boards.

Exp. The spark passes as explained in *ph.* 74, and according to *ph.* 79, and others, it will more easily leave or enter prominent parts than smooth flat surfaces.

PH. 114. To produce the greatest effect, a certain distance between the boards is requisite, greater or less as the power of the machine is so: a good machine being

employed, the greatest effect is produced when the boards are about one inch asunder, other things being the same. A less powerful machine requires a less distance, and a more powerful one a greater distance between the boards, in order to produce the greatest effects.

Exp. The state of the air, intensity of the conductor, &c. being given, a certain distance will determine the greatest effect, for if the boards be removed farther apart, the influence of the one on the other will be diminished, (*ph.* 102), and if they be placed nearer together the spark will pass between them (*ph.* 74 and 113), and will discharge them, so that a certain determinate distance is requisite for the greatest effect. Experiments shew that when the air is dry, and a good machine is used, the best distance is one inch; with a more powerful machine a greater distance will answer better, because in this case the striking distance, or that through which the spark can pass is greater, and the action on the air is greater and more extended. A more feeble power, as appears from the above observations, will require the plates to be at a less distance.

PH. 115. If the boards be placed about one inch and a half distant from each other, and the inner surface of the upper one be covered with gilt leather, instead of metal, and on the lower one be placed one or two small metallic hemispheres; and the one plate be connected with the positive and the other with the negative conductor: when the machine is in vigorous action, strong flashes with smart explosions will dart successively on one of the balls, and on the gilt leather, and there will appear beautiful and vivid coruscations of electric light, exhibiting the appearance of lightning, which indeed it is in miniature.

Exp. The greatest part of this is evident from the preceding explanations; the gilt leather, being a partial con-

surface, will suffer the spark to run along its surface, causing the coruscations. Here the upper board may represent a cloud, the lower one the earth, and the hemispheric balls, prominences, which are struck, or the two boards may represent clouds, and the sparks will give an idea of the lightning rushing from the one to the other.

Ph. 116. When the metal plates are separated by other more firm electrics, instead of the air, such as baked wood, resinous substances, glass, talc, &c. certain of these effects take place, and in this case the distances between the metals must be much less.

Exp. The charge is effected on the same principles as explained in *ph.* 110; the greater firmness of the bodies, and better non-conducting properties, require that they should be thinner, and hence the effect is greater for equal surfaces.

Ph. 117. These solid electrics also require a certain thickness for producing the greatest effect, when the electric intensity is given, the proper thickness depends on the power of the machine, and the nature of the substance. Glass of about $\frac{1}{20}$ of an inch thick is usually perforated by a strong charge, sealing-wax of the same thickness is also pierced, and often broken, baked wood is sometimes split, at other times the fluid finds its way through the pores in fine streams from one metallic surface to the other.

Exp. All these effects depend on the passing of the spark before explained, but there are some peculiarities arising from the nature of the bodies. Glass is the substance most convenient, and the best in many respects for concentrating the electric fluid; the phenomena attending its charging and discharging shall therefore be more fully developed.

Ph. 118. If a metallic plate, *c*, *fig*. 63, be placed on an

insulated glass plate *de*, and electrified by either a positive or negative conductor *a*, a bent wire proceeding from it to touch any part of *c*, or so near it that sparks may pass from its knob to *c*: then on moving the apparatus, and the metal *c*, by means of an insulating handle, it will be found, that the whole surface of the glass, which was covered by the metal, will remain electrified with the same power as that of the conductor.

Exp. First let the conductor *a* be positive, then the electric fluid will be diffused over the metal plate *c* by the spark or more so by the contact from the connection with *a*, and the contiguous atoms of the glass will therefore each receive some part of it, and retain it by its non-conducting property, so that it cannot pass along the glass (*ph.* 6). Hence, when the metallic plate is removed, each part of the glass, which it covered, is found to be in a positive state. Next, let *a* be negative, then the plate *c* will be deprived of part of its fluid, and the contiguous atoms of the glass will have their atmospherules extended towards it, and because of the contact will yield to it some portion of their electric fluid, and as before, the effect can only be transmitted to a small distance, as the loss of the contiguous particles of the glass cannot be supplied, it being a non-conductor; hence when the plate is removed every part of the glass, which it had covered, will be negative.

PH. 119. When the metal plate, as above, is in its place, the apparatus being removed from the machine, and a conductor connected with the earth is applied to it for some time, the surface of the glass will be restored to its natural state or nearly so.

Exp. A conductor easily yields its fluid to a body in a lower state, or receives it from one in a higher electrical state; hence the contiguous atoms of the glass will give

up their redundant fluid, or, if negative, receive a full supply, and in a certain time will be reduced to the same state as the metal disc in contact with them, and that is the natural state, because of the connection of the metal with the earth.

PH. 120. The glass plate being electrified as in *ph.* 118, and the metallic plate removed, if a conductor connected with the earth be applied to a part of the electrified surface, it will restore the natural state at that part, but not at the more distant parts.

Exp. The equilibrium is restored where the conductor is applied as in the last, but not at the other parts, because of the force of retention by which the fluid is not permitted easily to pass from one atom to another of a non-conducting body.

PH. 121. If the thin plate of glass be covered on both sides by metallic plates, as suppose by tin foil pasted on, so as to leave a margin on both sides all round at least of one inch, of which let AB, *fig.* 64, be a section magnified in thickness, C and G being equal metallic balls, C communicating with the conductor of the machine, and G with the earth. First, let AB be insulated and G removed; then the conductor of the machine being electrified to a given intensity, and the knob C at a suitable distance, a spark will pass between C and the coating, but after this no other spark will pass; the same intensity being maintained in C, which may be connected with either the positive or negative conductor, the other being uninsulated.

Exp. A spark will pass as explained *ph.* 74; suppose the conductor C is positive, then the coating B is also positive, the spark which it has received, being confined by the non-conducting power of the glass and air, is diffused over the metal, hence it presents a resistance to

the entrance of more fluid from C, so that it cannot receive from it another spark, while its intensity is the same.

If C had been negative, a similar explanation would apply, the spark, having in this case left B, renders it negative.

PH. 122. After the spark has passed between B and C, as in *ph.* 121, both the coatings of the glass are in the same electrical state, as the conductor to which C is attached.

Exp. First let C be positive, then the spark passes from C to the coating B, which therefore is rendered positive, and causes the atmospherules of the contiguous air to extend outward, as shewn at *c* by the short line; the atmospherules of the glass, for the same reason, are extended from B towards the opposite side, by the action of the fluid on the coating, as shewn at *r*, this propagates the like effect in the glass to a certain distance, as in the air, (*ph.* 104, and following,) although to a less distance; but here the glass being thin, its atoms are affected as far as the coating A, as shewn at *s*, and this most easily affects the fluid of the coating A, it being a conducting substance; hence the contiguous atoms of air have their atmospherules directed as at *d*, and therefore this coating will give the signs of positive electricity. When C is negative, the atoms contiguous to the coating will evidently, on the same principles, be extended, as shewn in the air at *a*, and in the glass at *m*, and as the glass is thin the series of its atoms will be acted on from the one to the other as far as the coating A, as shewn at *n*, and the air will have its atmospherules directed towards it, as at *b*, and both A and B will therefore be negative.

PH. 123. Let G, *fig.* 64, connected with the earth, be now placed near the coating A, and let the intensity of

C be maintained to the same degree by the action of the machine; then it will be seen, that when a spark passes between C and B, there will be one also between A and G, and several sparks will be produced in succession on each side, more or fewer according to the intensity of C, and the thickness of the glass.

Exp. The first spark will pass and produce the effects such as above shewn, (*ph.* 121 and 122), and G being now connected with the ground, will receive a spark from A, when C is positive, because A is rendered positive by its action, (*ph.* 122), so that the atmospherules of the air contiguous to A extend towards G, and produce the spark, (*ph.* 63 and 74), which having passed, the resistance to the action of the fluid on B, occasioned by the fluid on the surface A, is removed, and now consequently B is in a suitable condition to receive another spark from C, and this in the same manner as before will affect A, so that it gives another spark to G, and evidently, for each spark which passes, the quantity of electric fluid is increased on the surface of B, and diminished on that of A, and the power of B to receive, and of A to give the spark, continually decreases, till A no longer can receive a spark unless the intensity of C were increased, or the thickness of the glass diminished. When C is negative, similar reasoning holds good for the converse, the atmospherules being now directed the contrary way as shewn at *b*, *n*, *m*, and *a*.

Ph. 124. A certain determinate thickness of the glass plate is necessary for producing the greatest effect, when charged from a machine of a given power.

Exp. This will be evident on the same principles as explained in *ph.* 114. If the glass exceed a certain thickness, its atmospherules are not sufficiently affected on the opposite side; if too thin, its substance is broken

through by the force of the charge, as in *ph.* 74, the air was penetrated.

Ph. 125. Thick glass, which will take a strong charge by means of a powerful machine, will scarcely be affected by a feeble one, which last is, notwithstanding, capable of giving a strong charge to very thin glass.

Exp. This is easily understood by the preceding phenomenon; a powerful machine will sufficiently affect all the atoms of the thick glass to its farther side, and will therefore charge it; but a machine of small power will not affect them to such a degree, that a spark shall pass between the opposite coating and conductor connected with the earth, hence the conductor C, of low intensity, cannot charge the thick glass; but had the glass been very thin, the small power would have been sufficient to affect its atoms to the farther side, and thus to produce a considerable charge.

Ph. 126. The nearer the knobs C and G, *fig.* 64, are to the coating, the sooner and higher will the plate be charged by the conductor of a machine of a given power or intensity.

Exp. This arises from the less resistance of the smaller portion of air betwen the knobs and the coatings.

Ph. 127. If one of the knobs, as C, be connected with the positive conductor, and the other, as G, with the negative, the charge will be made sooner, and to a higher degree, than when one is connected with the ground.

Exp. The difference between the two conductors in their electrical state is greater than the difference between either of them and the ground, hence the effect in this case will be greater.

Ph. 128. If equal coated surfaces of thick glass, thin glass, and thin talc, be presented successively in the same manner to the conductor of a machine, it will be found

that they will charge to the same degree, as shewn by a quadrant electrometer, in different times; the thick glass by fewer turns of the machine than the thin glass, and the thin glass by fewer turns than the talc requires.

Exp. All this is a natural consequence of the preceding phenomena; the thick glass soon acquires on its nearest side the same intensity as that of the machine, or its conductor, since it cannot so far affect the opposite side, as to cause much of its fluid to be carried off; but in the others the process may be continued longer, because the fluid being more acted on, is more abundantly carried off from the opposite coating. The glass may be so thick, that it will not charge by the given power (*ph.* 125). It will then only receive one spark, and will shew by the electrometer the apparent full charge, the nearer side being of the same intensity as the conductor of the machine.

Ph. 129. While the plate is charging, both its sides are in the same electrical state as that of the conductor by which the charge is made, especially if the knobs C and G are not in contact with the coatings.

Exp. When the first spark has passed, this will be the electrical states of the two sides, (*ph.* 122), and it is on this account alone that the spark can now pass between A and G, and after this spark, the action of the next spark keeps up the same state as when the first spark had passed, which state must thus continue so long as the plate is capable of being farther charged, and that state will be afterwards maintained so long as the intensity of C is supported.

Ph. 130. The plate being charged and removed, the side which had been connected with the conductor will be found in the same electrical state with it, and the other side in the opposite state.

Exp. Suppose the conductor (*fig.* 64) by which the charge was made, and consequently C to be positive, then the side B, which was in connexion with it, contains a redundancy, and the other a deficiency of the electric fluid, yet both are positive, as appears from the preceding phenomenon; but on removing the plate, the charging force is removed, and the redundant fluid, which had been pressed on the atoms of the glass, tending to escape into the air, causes its atmospherules to expand outward, as at *c*, *fig.* 64, or at *d*, *fig.* 62, hence that side is still positive, and the pressure is in part removed from the opposite side A, *fig.* 64, on which account, as well as on account of its deficiency of fluid, the atmospherules of the contiguous air now tend the opposite way, that is, towards A, *fig.* 64, contrary to that shewn at *d*, and just as represented at *a*, *fig.* 62; and for a like reason the atmospherules of the glass are now directed towards B, *fig.* 64, and they are all extended the same way as at *a*, *b*, *c*, *d*, *fig.* 62, hence the side A is negative, and B positive. If the conductor C had been negative, the side A would contain a redundancy, and B a deficiency; and the like process of reasoning would shew, that the directions of the atmospherules of the atoms of the glass, and of the air on the opposite side, *viz.* *n*, *m*, *b*, would have been reversed, and all extended in the opposite direction to that represented in the figure, the same as that at *a*, hence the side B becomes negative, and A positive; the atmospherules of the glass and air all extend the same way, contrary to that of the short lines on *a*, *b*, *c*, *d*, *fig.* 62.

Ph. 131. If, when the plate of glass is fully charged, a person place one of his hands on one of the coatings, and then bring the other hand to the other coating, a strong spark will pass, and he will experience the sensation

called the electrical shock, and the plate will be discharged. The discharge is effected without the shock, by connecting the two coatings by any conducting substance; thus, if a wire, called the discharger, having a metal knob at each end, be bended, and one knob be placed on one coating, the other being then brought into contact with the opposite coating, the spark, or body of fluid, will pass through the metallic connexion, immediately producing the discharge.

Exp. The sides are in opposite electrical states by the last; let one knob of the discharger be put on the negative side, and make the other knob approach the positive coating, that knob then becomes negative, and the more so as it approaches the positive side, (*ph.* 62 and 63), till at a certain distance it will receive a spark, (*ph.* 74), by which the redundant fluid on the positive side is conveyed to that of the negative, and the equilibrium is nearly restored.

Ph. 132. The electric charge is retained and supported by the electric plate, and not by the coating, as appears by charging the plate by means of loose coatings; for these coatings may be removed and replaced either by the same or others, and the discharge may afterwards be made as usual.

Exp. The electric fluid thrown on the coating, when charging from a positive conductor, is spread over the surface of the coating, because it is a conducting substance, and the contiguous atoms of the glass, with which is is in contact, will receive a portion of the fluid (*ph.* 6), and retain it; and by its influence, through the medium of the intervening atoms, the opposite coating receives from the glass a portion of the protruded atmospherules, which is conveyed to the earth by the conducting communication; hence, when the coatings are

removed, the same electrical state is maintained on both the surfaces of the glass, and is only discharged when a conducting substance connects the coatings, while they are contiguous to the glass.

PH. 133. After the plate is discharged, and suffered to remain awhile, if the discharger be again applied, there is another slight spark; the fluid, which passes at this second discharge, is called the residuum.

Exp. At the first and principal discharge, the superficial fluid is carried from the positive to the negative side of the glass; but the equilibrium having been destroyed, not merely at the surface, but also at some little depth below the surface of the glass, and the resistance being now taken from one side, and added to the other, just at the surface only, there will follow, after due time, the more perfect equilibrium of the interior parts, which will produce a new small accumulation on the positive side, and deficiency on the negative, which is the residuum charge. The residuum is most notable of course on large coated surfaces.

PH. 134. The plate being charged with loose coatings, and these being afterwards removed, if the discharger be applied to the opposite sides of the bare glass, a partial discharge only will take place; *viz.* at the parts about the points to which the knobs are applied, and many applications of the discharging rod must be made to produce the equilibrium.

Exp. The non-conducting property of the glass, by means of which it is capable of acquiring and retaining the charge, prevents its fluid from escaping or entering at any parts but those near to which the discharging conductor is in contact.

PH. 135. If a charged plate of glass or jar be insulated, that is placed on an electric, as glass or resin, &c.

it may be touched on either side without a discharge, no more than a very small spark will pass at the one side or the other.

Exp. Suppose the positive side is touched, a very small spark will come fromi t, because it is positive, the pressure from the opposite side is therefore proportionately removed, and it becomes more strongly negative; but that side being insulated cannot receive additional fluid, hence that on the positive side is not farther pressed outward, and therefore its accumulated fluid cannot farther escape. The reverse happens when the negative side is touched.

PH. 136. If one side of a charged jar be touched, while the other is connected with the ground, the discharge is quickly yet gradually effected.

Exp. The positive side being touched, gives a spark, and the other becomes more strongly negative as in the last, and not being insulated, it now receives a portion of fluid from the earth, which increases the pressure on the positive side, so that it gives another spark, &c.; that is, the accumulated fluid passes off in a gradual stream, while the opposite coating is continually supplied from the earth. The reverse happens when the negative side is touched, the positive being connected with the earth. The shock may be experienced in this case, if there happen to be good conductors between the person and the place where the connexion is made with the earth.

PH. 137. When a charged plate is insulated, and touched by a conductor communicating with the earth, many times alternately on the opposite sides, it will be gradually discharged.

Exp. When the positive side is touched it yields a small portion of its fluid which passes to the earth, reducing the coating nearly to an equilibrium with the natural

state, and this removing a degree of pressure from the other side renders it still more negative (*ph.* 135); hence, the negative side being now touched by the conductor, a small spark of fluid is communicated to it, through the conductor from the earth, reducing it nearly to an equilibrium with the natural state, and this consequently presses the fluid more towards the opposite coating or positive side, which now again will yield a small spark, and this being given out puts the negative side once more into a state proper to receive another portion of fluid, and so alternately till the whole discharge is made.

Ph. 138. If the charged plate be well insulated, and placed in still dry air, it will retain the charge for a day or two, or, in some cases, for several days.

Exp. Since the plate is surrounded by non-conductors, the fluid has no means of freely passing from the positive side, or entering the other; and hence the equilibrium is restored by exceedingly slow degrees.

Ph. 139. If thin glass phials or jars (*fig.* 54) be coated inside and outside to within about two inches of the mouth, they receive the charge as well as plates of glass, and in most cases are more convenient for electrical experiments.

Exp. The charge, according to the foregoing explanations, does not depend on the form, but on the quantity of surface, and the thinness of the glass.

Obs. The jar is generally furnished with a wire passing through the cork, or stopper, and terminated by a small chain within to communicate with the inner coating, and to the other end is attached a knob or hook to connect it with the conductor.

Ph. 140. If a jar be suspended by its hook, or otherwise attached to the conductor, and suspended in the dry air, it will scarcely receive any charge.

Exp. For the fluid, thrown on the inside, causes that on the outside to extend outward, which for want of a conducting medium to the earth remains there and becomes a resisting force (*ph.* 121), and prevents the accumulation within, and hence the jar does not receive a charge.

Ph. 141. If a jar or phial be connected with the conductor as in the last, and a fine pointed wire be fixed on the outer coating so as to project from it, the phial will receive the charge.

Exp. If the conductor, to which the phial is connected, be positive, the wire (*ph.* 32 and 37) throws off the fluid, and if negative receives it readily, (see *ph.* 121 and 122, the effect of points will be more fully explained), hence the charge will be produced, as when the spark is given, or a communication made with the earth.

Ph. 142. If a point, instead of projecting from the coating, be presented towards it at the distance of three or four inches or less, the jar will in this case receive a charge, although a knob at that distance would have been ineffectual.

Exp. The point so presented also (*ph.* 32 and 37) receives or emits readily a current of electric fluid, by which the process of charging advances and is completed. The effects of pointed conductors will be shewn *ph.* 184, and following.

Ph. 143. If a series of jars be so disposed, that the knob of the first may be presented to the prime conductor, and the knob of each succeeding one be in contact with the outer coating of that which precedes it, and the coating of the last be connected with the ground; then, on turning the machine, the whole series of jars will be charged in a similar manner, that is, all positively in the inside, if the first knob be presented to the positive con-

ductor; and the contrary if it be presented to the negative conductor.

Exp. When the first knob receives a spark, the communicated fluid is diffused over the inner coating of the first jar, and causes a tendency of that which is on the outside to escape, as before explained; this tendency, through the medium of the connecting conductors is propagated to the interior surface of the next jar, which therefore will affect its exterior coating, giving it a like tendency to escape, and thus, because of the conducting connection, the effects will be transmitted through the series, and from the last jar to the earth; and this passage of the fluid to the earth puts the series into a state fit to receive another spark from the conductor, as already abundantly shewn, the process continuing till the charge is completed according to the power of the machine, and evidently the charge in all the jars will be of the same kind.

Ph. 144. If the knob of a jar be presented to one conductor of a machine and its exterior coating, or that of the last of a series of jars, as in the last phenomenon, be connected with the other conductor, the charge will be effected more rapidly than when the last is merely connected with the earth.

Exp. The conductor if negative receives the fluid and if positive gives out the fluid more freely than the earth which is in a natural state, and hence arises the greater facility in charging.

Ph. 145. If the outside coatings of several jars be connected by a conducting substance; and the knobs by another conductor, the whole apparatus or battery becomes charged in the same manner as a single jar, by connecting one side with the conductor and the other with the earth, or with the other conductor of the machine.

Exp. The connections of the coatings render them the same as two single coatings of greater surface, and hence they are charged according to the same process.

Ph. 146. When the glass is fully charged, other things being the same, the shock, and force of the fluid will be stronger as the surface is greater.

Exp. Since the glass is fully charged, and of the same kind and thickness, the accumulated fluid on one side will be as the surface, and since it is discharged at once, the greater the surface the greater will be the shock, on account of the increased quantity of the fluid which passes from the one side to the other.

Ph. 147. The strength of the charge of coated glass frequently depends also on the state, quality, and size of the machine by which the charge is communicated.

Exp. According to these circumstances the conductors will be, the one positive and the other negative, in a higher or lower degree, and consequently will communicate a greater or less quantity of fluid to the surface connected with it, and this will affect the opposite side according to its intensity, and thus give a greater or less charge.

Ph. 148. The more powerful a machine is, the more rapidly a given quantity of coated surface will be charged.

Exp. For the conductor gives larger and more frequent sparks, because the more powerful machine supplies a greater quantity of fluid in the same time.

Ph. 149. With a given machine the larger the quantity of coated surface, the longer will be the time of charging.

Exp. For in this case the sparks communicated are diffused over a larger surface and hence cannot affect each part to the same degree as when the surface is less, hence a longer time is requisite.

Ph. 150. If the discharging rod (*ph.* 131) be applied to connect the sides of a strongly charged jar, while fur-

nished with balls at its extremities, a strong flash and loud report is produced; but if the balls be removed and the extremities terminate in fine points, there will be but a faint stream of light and very little sound.

Exp. When the balls are applied the air is affected strongly between the surfaces of the ball and jar, and nearly the whole body of fluid passes at once between them, and hence the large spark which suddenly displacing a considerable body of air causes the sound: when the points only are presented, the air is very powerfully affected, yet only in a line or small space between them, and hence the fluid flows in a gentle rapid stream, hence also the light and sound are feeble.

PH. 151. In discharging a jar, the shock is found to pass from the one side to the other through good conductors, even when the circuit is of a great length, in a very small portion of time.

Exp. The jar being fully charged, at the moment the discharging rod is applied, imagine that the several atoms of the electric fluid are kept in their places by some restraining force; now the centers of these atoms are pressed far within the spheres of each other's repulsion by the action of the tenacious atoms on them; but this is much more so on the positive than on the negative side, the fluid there being more dense than in the natural state, while it is less dense on the other side; and because by means of the discharger there is a complete connection between the sides without any opposition to an equilibrium, except the supposed restraining force; as soon as that is removed, the action takes place at once through the whole line of connection, restoring the equilibrium: from this it will appear that the discharge will be acconplished in a space of time almost inappreciable.

Obs. It is not to be supposed that all the fluid, which

has entered the negative side, has actually come from the positive side, part of it is what naturally belonged to the discharging rod, which portion is replaced by that which escapes from the positive surface : so that probably when the circuit of the discharging conductor is very extensive the negative side is entirely supplied from the circuit.

Ph. 152. When a considerable number of persons join hands, and form a circuit for the discharging of a jar, all receive the shock apparently at the same time; but those towards the middle receive it less forcibly than those who are nearest to either extremity.

Exp. The difference between the intensity of each of the charged surfaces, and the adjoining extremity of the circuit is greater than between the parts at the middle which is nearly in its natural state, hence the fluid will pass at the extremities in a more condensed form, and with greater force, than in the middle, where it will be more diffused and consecutive. This phenomenon tends to confirm the observation on the preceding.

Ph. 153. When the sides of a charged jar are connected by two circuits, the discharge is made through the best conductor, although it should be much longer. Thus the discharge will be made through 70 thousand inches of wire sooner than through 10 inches of wetted pack-thread.

Exp. In each circuit there is situated a continued series of electric fluid, but it is retained in its place by the wetted packthread with much greater force than by the wire, because it is a much worse conductor, hence it passes chiefly through the wire, which therefore is the medium by which the main body of the fluid attains an equilibrium.

Ph. 154. When the discharge is made through two circuits, both conductors but in different degrees, as above, some small portion of the fluid will be transmitted through

the worse short circuit, as, for instance, through the wet pack-thread.

Exp. At the moment of the discharge there is a force of all the atoms of the fluid operating in the lines of connection between the sides of the jar, hence some portion will pass along the pack-thread, or worse conductor, more or less according to its conducting power.

PH. 155. If a long wire be bended into a curve, so that its parts near each extremity may approach each other, when the discharge of a large jar is made through this wire, a spark passes through the air where the wires are nearest together.

Exp. This agrees with *ph.* 154, the very short portion of air being a conductor to powerful electrical forces (*ph.* 8 and 9), and a passage is prepared by the position of the atmospherules of the air between the wires, allowing the spark to pass.

PH. 156. Things being as in the last, the stronger the electrical charge is, the greater distance will the spark pass through the air between the less distant parts of the wire; thus a strong shock will give a spark through the air, if the wires be a quarter of an inch asunder, while a weak shock will not do it at the distance of $\frac{1}{8}$ of an inch.

Exp. Bodies, which are non-conductors to the electric fluid of small intensity, are conductors when the intensity is greatly raised, (*ph.* 8 and 9), which accounts for the facts here mentioned.

PH. 157. Things being as in the two last, the smaller the wire, to the greater distance will the spark pass in the air.

Exp. In a small wire the passage of the fluid is in a spark more dense than in a thick one, because of the more contracted course on the small wire, and hence the greater force of repulsion between its atoms will cause it to take more readily a passage through the air, where the parts

of the wire are nearest; on this account the spark will strike through the air at a greater distance when the small wire is used, than when the thick one makes the circuit.

Ph. 158. The force of the shock is weaker when it passes through several circuits at once, and the diminution is greater at the parts most remote from the extremities.

Exp. The force is diminished, because the equilibrium is not restored at once, for however short the time of the discharge it is not equally short through good and bad conductors, and it is most diminished in the intermediate parts, because of the divided state of the fluid in the different routes.

Ph. 159. When a large thin jar, or several such jars, connected as in a battery, is highly charged, and then discharged by a good short conductor, the glass is frequently pierced at the place where the discharging rod is applied: but if the charged jar be placed on a metal plate, and the rod applied first to this plate, and then to the knob of the jar, the glass is seldom fractured.

Exp. The reason of the difference in the effect is easily seen; for in the first case the fluid of the charge is concentrated at the place of application of the discharger at one point of the glass, but in the second case at a point on the metal plate distant from the glass, which it consequently enters in a less condensed form.

Ph. 160. When a jar or battery is very highly charged, the glass will sometimes be perforated while standing, after the charge is completed.

Exp. By very slow degrees the electric fluid will make a small advance within the surface of the glass from the positive side towards the negative, when the intensity is very great, hence the effect here mentioned in some cases may evidently be produced, especially if some parts of the glass be thinner than the rest, or in other respects faulty.

PH. 161. If both the surfaces of a jar be made moist with watery vapour, the jar will scarcely receive any charge.

Exp. The moistened surfaces of the glass serve as a conducting medium, so that the equilibrium cannot be destroyed on the two opposite coatings, the fluid passing from one side to the other while of low intensity.

PH. 162. If both sides of the jar be made very dry, and especially if the glass be a little warm, the jar will frequently be discharged with an explosion during the process of charging, and before it is completely saturated. This is called the spontaneous discharge.

Exp. The glass and air are good non-conductors, particularly the former; hence the fluid will be chiefly confined to, and condensed over the coated surface, and most of all it will be accumulated at the thin edges of the coating on the inner or positive side, and the contrary on the other side; hence, the air will be affected chiefly along the surface of the glass from the edge of the inside coating to that of the outside, and at a certain period of the charging the spark will pass from the part most favouring its transmission, that is, from the prominences of the coating, and this will restore the equilibrium.

PH. 163. If the inside of the jar be made moist by breathing into it through a tube; and the outside be quite dry, it will receive in charging much more fluid without the spontaneous discharge, and will give a shock of much greater force.

Exp. The moisture, adhering to the glass and to the air within the jar, renders them partially conductors, hence a portion of the fluid will be diffused over the interior of the uncoated part of the glass on the inside, which from its partial adherenc to the glass, and particles of the contiguous air, will re-act as a resisting force against the

fluid accumulated over the coated surface, and hence the jar will take a much higher charge without spontaneous explosion.

Ph. 164. If instead of breathing into the jar, a small zone of paper, or other partially conducting substance, be applied round the glass, at the upper edge of the coating, the spontaneous discharge will be prevented.

Exp. This is explained as the preceding, for the fluid which in part adheres to this upper rim of paper, or other suitable substance, resists the passing of the spark which produces the spontaneous discharge.

Ph. 165. If a jar be charged at the positive conductor, and afterwards be presented to the negative conductor, after a few turns of the machine it will be discharged, and if the process be continued it will soon acquire a negative charge. It is to be observed, that when one conductor only is employed, the other must be connected with the ground by a conducting medium.

Exp. When the jar, charged at the positive, is afterwards presented to the negative conductor, it yields to it a spark more readily, than if it had been in its natural state, the earth quickly supplies its outside, and it gives other sparks in succession; hence the equilibrium is soon restored, and the same process being continued, the fluid goes from the inside, and is supplied to the outside till the maximum effect is produced, and the jar is charged negatively.

Ph. 166. Let two equal jars be charged at the same time, the one at the positive, and the other at the negative conductor, to the same degree; place them on insulated stands, connect their knobs by an insulated discharging rod, and there will be no discharge; remove the rod, and apply it to the coatings, and still the discharge will not be produced.

Exp. The knobs being connected, a small portion of the fluid passes from the positive side and knob of the first jar, to the negative one of the second: now the outside of the first, being insulated, receives no supply from the earth; and hence the tendency of the fluid to escape from the inside ceases, also no fluid can escape from the positive outside of the second jar to the earth, hence it resists a further addition to the inside; thus, on both accounts, the discharge cannot be made. The explanation is the same when the outsides are connected.

Ph. 167. When the outsides of the two insulated jars charged, one negatively and the other positively, as above stated, are first connected by a conductor, and the discharging rod then applied to the knobs, an explosion will take place, and both the jars will be discharged.

The same would also be effected by first connecting the knobs, and then applying the discharger to the outside coatings.

Exp. The outsides being connected, when the discharging rod is applied to the knobs, as in the last explanation, a spark would pass from the positive knob to the other, but now the fluid can freely pass from the positive outside of the second jar to the negative outside of the first; hence, instead of a small portion passing as there shewn, the fluid will advance in a bod and the equilibrium will be at once restored. The same reasoning applies to the second case.

Ph. 168. If one of the jars be charged, and the other of the same size and thickness be not electrified, and if then the outer coatings be connected by a conductor, and the insulating discharger applied to connect the inner sides by touching the knobs, the charge will be equally divided between the two jars.

Exp. The electric fluid will tend to leave the positive

side of the charged jar, and its negative side will tend to receive the fluid; hence, when the connexion is made as above, it is manifest that the fluid will leave the positive inside and enter the other jar, which will consequently yield a portion to the negative surface of the first, thus in part charging one and discharging the other, and this process continues till there is an equilibrium, that is, till the jars are equally charged.

PH. 169. The two jars being equalized and connected as in *ph.* 168, if a discharging rod be applied to one of the outer sides, or to the connecting conductor, and then brought to one of the knobs, or to any part of the medium connecting the knobs, both jars will be discharged. The same quantity of electricity nearly will pass as if the one jar had been discharged before equalizing them, but it will pass with less force.

Exp. The entire discharge will take place for the same reason as that of a single jar, and evidently the same quantity of fluid will pass, except the very small portion which may have been dissipated; and the force of the shock will be less, because from the diffusion of the same quantity on a greater surface, the intensity, and consequently the force of its motion is less.

PH. 170. When the two equal jars are charged in unequal degrees, and the process of *ph.* 167 performed, the explosion will still take place, but the jars will not be totally discharged.

Exp. Suppose the positive jar to be charged in the highest degree, and let its fluid be supposed to be divided into two parts, of which one is equal to the charge of the other jar; then, on making the connexion, this part will produce an explosion, and be equalized as in *ph.* 167; and the remaining part will be equally divided between the two jars, as in *ph.* 168.

Ph. 171. If two equal jars be charged to the same degree, both at the same conductor, and if they be connected, suppose by a chain, at the outsides: then, if the knobs be brought into contact, there will be no explosion.

Exp. Since the jars are already charged in an equal degree, they will continue so as was observed of the jars in *ph.* 168, after they were equalized.

Ph. 172. Things being as in *ph.* 171, if the knob of the first jar be brought to the coating of the second, a strong explosion will be produced; and if now the knobs be brought into contact, there will be another smart explosion; and after this, if again the knob of the first be applied to the coating of the second, there will be another less explosion; the knobs will then give a fourth explosion, and thus alternately, always after the contact of the knobs applying the knob of the first to the coating of the second; in this way ten or a dozen sparks may be obtained in succession, continually diminishing till they are only just perceptible.

Exp. When the knob of the first jar is placed in contact with the coating of the second, there is a metallic communication between the inside and outside of the first jar, which is therefore discharged, while the second jar retains its fluid: when the knobs are then made to touch, the jars are equalized as in *ph.* 168. The remaining part of the operation is only a repetition of this process, and the second jar is discharged by small portions at a time; that is, the half of what is left in it, is taken off at each application of the knobs to each other.

Effects of the Electrophorus.

Obs. The charging of coated electrics, and the electrifying of bodies by induction being well understod, it will not be difficult to comprehend the properties and effects of the electrophorus, which is an instrument consisting of two metallic plates, and a plate of some non-conducting substance to be placed between the two others.

The lower conducting plate may be placed on an insulating stand and may thus be insulated or not at pleasure, as *ab*, *fig.* 55, it is called the sole. The other metallic plate, called the cover, is furnished with an insulating handle as *cd*, *fig.* 55; to move it to or from its place. The electrical plate may be glass, or some resinous substance which answers better, it is placed on the sole, *ab*, and the cover *cd* is put on, or removed as occasion may require. Sometimes the resinous substance, when melted, is poured on the sole, making a coating of about half an inch thick. Equal parts of shell-lac, resin, and Venice turpentine form for this purpose an excellent composition. It is to be melted together, and formed into a plate about half an inch thick by pouring the mixture whilst fluid within a hoop of the required size placed on a marble table, from which it easily separates when cold.

Ph. 173. Let a smooth glass plate be placed on the sole *ab*, *fig.* 55, and its upper surface excited, by rubbing it with fur, silk, or flannel, *ab* will be in a positive state, as shewn by the balls *m n*.

Exp. The glass by the excitation is positive on the upper side, hence there is a tendency for the fluid to escape on the other side, and being in contact with the

conducting body *ab*, it causes part of its natural quantity of fluid to extend outward, so as to be ready to communicate a spark, hence it is positive.

PH. 174. Things being as above, let the cover, held by its insulating handle, be brought over the electric plate, and as it approaches it, the balls *m n* will continually diverge less, and when *cd* is near the glass plate the signs of electricity cease in *ab*; if *cd* be brought still nearer, the balls diverge with negative electricity, and *cd* becomes positive.

Exp. As *cd* approaches the plate, its upper side becomes positive and its under side negative, and the more so as it is nearer, (*ph.* 62); hence the excited electricity on the upper side of the glass plate extends the more upwards, and presses less on the lower side, and the electrified air near the glass contributes to this effect. Therefore when the plate is at a certain distance, the glass ceases to give signs of electricity to the lower plate *ab*. Now some small portion of electric fluid had been dissipated from *ab*, while in its positive state, and the resistance being removed, by the extension of the fluid towards and on *cd*, it follows when *cd* comes very near the glass it becomes strongly positive, and *ab* appears in a negative state.

PH. 175. If *cd*, *fig.* 55, be raised again, it is found in its natural state or nearly so, and the several parts of the apparatus return to the condition they were in, before the cover was placed on the glass plates, with a small diminution of effect; and the process may be repeated several times.

Exp. While the cover was on, or very near the glass plate, it was affected by it; the electric atmospherules of the atoms of the excited glass extended towards it, and pressed its natural fluid towards the opposite side (*ph.* 62) making it positive, the electric fluid of the air contri-

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may be repeated as long as the glass plate remains
electrical.

Ph. 177. The effect may be increased thus, while the cover is on, as in *ph.* 174, touch the lower plate *ab*, then touch the upper plate, remove it by means of the handle, and it will now receive a larger spark than when treated as in *ph.* 176.

Exp. While the cover is on, the lower plate *ab* is negative (*ph.* 174), therefore if touched by a conductor it will receive a spark, hence the positive state of the cover *cd* is increased, and it will yield a greater spark than if *ab* had not been touched, hence having lost a greater quantity of its fluid, it will receive a stronger spark when separated to restore its equilibrium.

Ph. 178. The plate of the electrophorus is usually made of the resinous composition described in the *obs. page* 244, this substance being on several accounts preferable to most others,—it is more easily excited, moisture does not adhere to it, and it retains the excited electricity longer than most other electrics. When applied and excited as in the preceding phenomena, it exhibits all the effects of the glass plate in a reverse order, that is, the parts, which in the preceding five cases were positive, are when the resinous plate is used, negative, the resin being excited with dry fur.

Exp. The resinous plate thus excited, is itself negative on the upper side, as before the glass was positive, hence we shall have similar effects in a reverse order, and similar explanations apply.

Ph. 179. When the resinous plate is excited, and the cover *cd* put on, if the knob of an uncharged jar be presented to the sole *ab* it receives a spark and a small positive charge.

Exp. The sole *cd* is positive in this case as it was negative in *ph.* 174, hence the reason of the effect mentioned.

Ph. 180. The effects of the electrophorus are greater when the sole is uninsulated than when insulated, and still greater if it be connected with a negative conductor.

Exp. The effect is increased by connecting the sole with the ground as shewn *ph.* 177, and in that case it would have been still farther increased by connecting it with a positive conductor, because it would yield a readier supply than the earth, so here the effect is increased by the negative conductor, for the electrical state of the sole being reduced, the cover is rendered still more negative.

Obs. When in general use the sole is uninsulated

Ph. 181. When the cover is on the excited resinous

plate, the sole being uninsulated, or connected with a negative body, if the knob of an uncharged jar be presented to the cover, it will obtain a small negative charge.

Exp. The cover, being negative, receives a spark from the knob while the outside of the jar is supplied from the earth, and thus the effect is produced.

PH. 182. Things being as in the last, if the cover be raised by its handle, and the knob of the jar, which had been charged by it, be presented, the jar will be discharged.

Exp. The cover having received a spark from the knob (*ph.* 181) when removed is positive, and now will give as much fluid as it had received, and hence both it and the jar are restored to their natural state.

PH. 183. If the cover be placed on the excited resinous plate and touched by a conductor, and then removed by the handle, it will give a spark to an uncharged jar, and this may be repeated several times successively, till the jar receives a strong positive charge, and several jars may be charged by once exciting a good electrophorus.

Exp. The reason of this will be very evident from a consideration of the preceding phenomena relating to this subject; for the resinous plate loses very little of its fluid by the several operations.

Effects of pointed Conductors.

PH. 184. When a finely pointed conductor, as a pointed wire, projects from an electrified body, it has a powerful and rapid effect in restoring the equilibrium, especially if a conductor, communicating with the earth, be placed before it at some moderate distance. The same happens if

the wire be held pointing towards the electrified body, even at a considerable distance, especially if the point be uninsulated.

Exp. The reason of this will appear from *prop.* 17 and its *cors. sect.* ii, and from *ph.* 24, 32, 37 : and more fully thus; suppose the uninsulated point is the extremity of a wire presented to a body in a positive state, for instance to the positive conductor of an electrical machine; then the atmospherules of the air are directed outward from the electrified body (*prop.* 27, *sect.* ii.), and consequently towards the point (*ph.* 62), and the more so when the point is uninsulated (*ph.* 63); hence the point becomes involved in the atmospherules of the adjacent atoms of the air, as shewn by the short lines at *b*, *fig.* 67; and because the point is negative (*ph.* 63), a portion of the fluid will escape from these atoms and pass along the wire opening a way for a current through it. When the fluid leaves an atom of air, and enters the wire, a repulsion takes place between them, greater or less according to the quantity separated, (*prop.* 14, *cor.* 9, *sect.* ii.); hence the atom of air recedes in the opposite direction; also this discharge of the fluid from the air causes the atmospherules of the contiguous air to extend still more towards the point, the resistance to that effect being in part removed, and therefore the fluid still more readily enters the point from the atoms of air which take the place of those that have been repelled, the motion itself of the air contributing to the same end; from all this it will evidently appear that the point must carry off the fluid rapidly. Next let the pointed wire be presented towards the negative conductor, or the cushion of the machine; in this case the atmospherules of the air are directed towards that conductor (*prop.* 28, *sect.* ii), and those of the air, contiguous to the wire at its extremity, will be more extended

towards it from the wire, (*ph.* 62 and 63), while at *a*, *fig.* 67, it will extend from the wire, and a quantity of fluid will be protruded, and pass off at the point, since the adjacent air is in a state fit to receive it. Now when a portion of the fluid passes from the wire to an atom of air at its extremity, a repulsion occurs, as before (*prop.* 14, *cor.* 9), and the air recedes, this causes the atmospherules of the contiguous air below the point *a* to incline the more from the wire; and the transmission of the fluid is accelerated, and thus the point tends rapidly to restore the equilibrium. When the point projects from the body the explanation is similar, the one case being that in which the wire receives, and the other that in which it gives out the fluid.

PH. 185. Several points placed near each other have a less effect in restoring the equilibrium than a single point; thus M. *Achard* found that a single pointed wire, screwed into the center of a circular piece of brass one inch and a half in diameter, produced a greater effect in transmitting or receiving electricity, than nine similar points, screwed into the same base, the proximity of the nine points occasioning them to act nearly as one conducting surface of the same area.

Exp. The atmospherules of the atoms of the air, situated between the points, are as much influenced to extend towards the one as to the other point; and hence are so balanced as not only to preserve their own fluid, but to prevent the accession and transmission of the adjoining atoms of the air, and thus the effect is diminished by the approximated points.

PH. 186. If a fine point be inserted into a large ball, so that it can be protruded more or less; it will be found, that when the point is within the surface of the ball, it has no effect in altering the state of equilibrium, but in

proportion as it is protruded more and more without the surface, it increases continually the transmitting power, till it attains the full effect of a naked point.

Exp. The fluid tends to the surfaces of conductors, (*ph.* 29 and 30); hence, the point within the surface of the ball has no effect in transmitting the fluid. When the point is projected but a very little, the atmospherules of the air, which would have been deflected to the point, are now in part turned towards the ball, and the action of the point is on that account feeble; but evidently, from the explanation of *ph.* 184 and 185, it becomes more and more effective, as it is farther advanced from the ball.

PH. 187. The finer the point, and the more freely it projects from any round or flat surface, the more rapidly it will receive or transmit electricity.

Exp. An attentive consideration of the three preceding phenomena will shew the reason of this; the effect of such points is to prepare and open a passage for a fine, rapid, and continued stream of the fluid.

PH. 188. If a tuft of feathers, or a piece of fur, be fastened to the end of a wire, and the other end be inserted into the conductor of a machine, the fibres will diverge by mutual repulsion: present a pointed wire, and they will shrink, and appear to cling to the wire to which they are attached; remove the point, they will expand again, and thus alternately.

Exp. The repulsion between the fibres arises from their being similarly electrified, *ph.* 84; the point rapidly carries off their electricity, *ph.* 187; hence, it repels them, *ph.* 85, and their own wire attracts them, *ph.* 84.

PH. 189. If a fine conducting point or wire project from an electrified body, or be presented to it as in *ph.* 184 and 187, a sensible wind, or blast of air, issues

directly from it, sometimes sufficiently strong to blow out a candle.

Exp. When the electric fluid passes from an atom of air to the point, or from the point to an atom of air, a repulsion, or re-action takes place between them, (*prop.* 14, *cor.* 9, *sect.* ii), as was shewn, *ph.* 184; hence arises a current of air, from the successive repulsions of the atoms giving or receiving the fluid, in the direction from the point, whether it receives or gives out the electricity.

PH. 190. If two points be held towards each other, one connected with the conductor and the other with the earth, they will blow against each other.

Exp. This depends on similar circumstances as noticed in *ph.* 189, and proceeds from the same cause.

PH. 191. If one or more wires be nicely balanced on an upright pointed wire, projecting from the conductor; and if the ends of the wires be pointed and turned at right angles, and disposed so as to be in, or nearly in the same horizontal plane, the points being turned the same way in respect of a line from the center, the instrument, which is called the electrical fly, will revolve by electricity in a direction opposite to that of the points.

Exp. This follows from *ph.* 189; for the repulsion or re-action between the air and the point, in consequence of the passing of the fluid, is equal and contrary; hence, the points being now free to move, will revolve in a direction contrary to that of the motion of the air.

PH. 192. If the electrical fly uninsulated, be held near the electrified conductor, it will revolve as before.

Exp. This will be understood from the preceding explanations.

PH. 193. If the same instrument be held near the revolving glass cylinder of the machine, it moves with still greater velocity.

Exp. The electric fluid in this case passes to the point in greater portions at a time, and thus produces a greater effect.

Ph. 194. If the electrical fly be electrified in the exhausted receiver of an air pump, it will not turn by the action of the points.

Exp. The fluid in this case does not pass in little portions or sparks to the air, because of the absence of the greatest part of it, and the fluid is now more diffused. This confirms the preceding explanations.

Ph. 195. If the fly be merely covered with a glass receiver, the motion is very slow, and the receiver becomes charged.

Exp. The electric fluid delivered by the points, charges the air within the receiver, and consequently the glass, and hence there is a resistance to its further extrication from the points, and therefore the motion is but little, and soon ceases. If the points of the fly receive the fluid, the air and glass are charged with the contrary power.

Ph. 196. If while the electrical fly is in the unexhausted recipient, as in *ph.* 195, it may be made to move either way, by touching the outside of the glass by an uninsulated conductor.

Exp. This arises from electrical attraction. Where the outside of the glass is touched, a portion of fluid is carried off, or added, according as the fly gives out or receives the fluid, as is evident from the phenomena respecting charged electrics; and hence the attraction arises, for the opposite side of the glass, when touched, attains the opposite power, and therefore the nearest arm of the fly is attracted.

Ph. 197. If a few pasteboard vanes be fixed in a cork, and a needle be inserted as an axis, and suspended by a magnet; then, if this little instrument be so held, that

the electrified point shall be directed towards the vanes, it will be put into rapid motion. On this principle, many mechanical models have been constructed and made to move.

Exp. This effect evidently arises from the blast of wind, or air, issuing from the electrified point, the reason of which has been already shewn.

Exhibition of Light.

Ph. 198. When bodies are intensely electrified, flashes of light, and scintillations, are frequently seen about them, especially in dark places, and at the extremities of pointed conductors.

Exp. When the body is thus intensely electrified, the atmospherules of the atoms of the surrounding air are so much extended, that the electric fluid passes between them, (especially from or to the more prominent parts), and the action between the atoms in this transit will dissipate in every direction some portion of the ethereal atmospherules of the atoms of air in radiations, and hence the light, which forms part of those atmospherules, is evolved.

Ph. 199. When, instead of a point, an uninsulated ball, or round body, is presented at a suitable distance to the electrified conductor, whose intensity is supported by the action of the machine, the fluid passes between them at intervals in a body, exhibiting sparks more or less intensely luminous according to circumstances.

Exp. The passing of the spark has been explained, (*ph.* 74), and the air is acted on by the rapidly moving

body of fluid, so that from the fluid itself, and from the atmospherules of the air which receive the sudden impression and concussion, the light is made to radiate, the centers of the ethereal matter being driven so deeply into each other's spherules, and into those of the tenacious atoms, that the requisite velocity is communicated.

Ph. 200. When the spark passes through a long distance it is of a zigzag form; but when the distance is short, the spark proceeds nearly in a straight line.

Exp. When the distance is great, the body of fluid by its rapid progress compresses the air before it, and hence the resistance in its direction becomes greater than the lateral resistance; hence it deviates from its course at intervals, as it advances, and produces the zigzag motion; but when the distance is short, the resistance does not become sufficiently powerful to deflect it from its course, which is marked out by the previous position of the atmospherules of the air. See *fig.* 65, where the dotted line AB shews the direction of a short course.

Ph. 201. When the spark is passed in rarefied air, the course of the spark becomes more rectilineal.

Exp. This will follow, because the resistance to its direct progress does not become sufficient to cause much deviation from a right line.

Ph. 202. "In condensed air the light produced by the electric spark is white and brilliant; in rarefied air, divided and faint; and in highly rarefied air, of a dilute red or purple colour."

Exp. The difference in the sorts of light may arise from a difference in the forces and spherules of that ethereal matter, or from a difference in the force of projection, and consequently in the velocity of its motions; or the difference may arise from all these circumstances combined: and experiments on light shew, that the red light

proceeds with greater force than the purple or violet, and therefore requires a greater force of projection; but in dense air the resistance, as well as the number of atoms of air, is greater, and hence the stronger as well as the weaker light will be copiously projected together, which will produce the brilliant white light; but in rarefied air only some sorts will be caused to radiate together, and the different sorts alternately, according to the oscillations and vibrations produced in the rarefied air by the action of the fluid; hence the dilute diffused light, and the colours.

Ph. 203. As the air becomes more and more rarefied, it more easily transmits electricity; and the light appears at a lower intensity, but more dilute.

Exp. The conducting power is explained *ph.* 13; and as a more easy passage is afforded to the electric fluid, so the light is produced more faintly, and at more widely distant points, but not so copiously, because of the less force of the electricity.

Ph. 204. Continuous conductors of sufficient size transmit electricity without affording light; but if the conductor have slight intervals between its parts, a spark is seen at each separation.

Exp. For in the case of continuous conductors, the electric fluid moves through the exterior stratum of the conductor, without the intervention of the atoms of air; but when there are short spaces of air between its parts, the electric fluid passes from the conductor to the contiguous atoms of air, and from them to the next part of the conductor; and hence the spark and light are seen at each interruption as above explained.

Ph. 205. If an extended pointed wire project from the positive conductor, or be presented uninsulated to the negative conductor, the machine being in action in an

obscure place, a beautiful luminous flame will issue from the point, exciting a vibratory motion in the air, with a slight crackling noise. If the point project from the negative conductor, or if it be presented towards the positive one, we shall merely see a luminous point at the extremity of the wire.

Exp. According to our principles, the point, in the first two cases, is giving out the fluid, and the atmospherules of the air will be extended from the point (*ph.* 65 and 184) as shewn at the point *c a*, *fig.* 67, the action being from the part *a* of the wire; hence the fluid will dart from the point to the air on all sides about it, in an expanded and diffused form, causing the air to dart a little sideways, as well as directly from the point; this will produce the brush or plume of light, the vibrations of the air, and the crackling noise.

In the second two cases the point is receiving the fluid, and the atmospherules of the air are directed towards it as at *b*, (*ph.* 63 and 184); therefore, the point itself is involved in the several atmospherules of many atoms of the air, the fluid is therefore carried off very rapidly at the extreme point, the air is projected directly from the point, and other atoms of air press there, so that a dense star of light only is seen at the receiving point.

Ph. 206. If a coated pane of window glass have a pointed wire projecting outward, from each coating, and one point be presented towards the positive conductor of a machine in action, a star of light will be seen at that point, the room being darkened, and a pencil of diverging rays at the other. If the point had been presented to the negative conductor, the pencil of rays would be seen on it, and the star on the other. In both cases the plate of glass would be charged.

Exp. It is manifest, from the phenomena of charging,

that the point which shews the star is receiving the fluid, and the other throwing it off, and the whole agrees with all that has been advanced respecting the charging of electric plates, and the action of points.

Ph. 207. When the plate is thus charged and removed, the point, which while charging shewed a star of light, now exhibits the plume; and the appearance of the other point is also reversed, and the plate is soon discharged.

Exp. The fluid has a tendency to escape from the positive, and to enter the negative side; this is gradually and speedily effected by means of the points, and all the effects agree with the preceding phenomena.

Ph. 208. If when the plate, when fully charged, as in *ph.* 205, be reversed, so that the points may be in the opposite direction, the effect is much more violent; and it is surprizing to observe with what rapidity one point receives, and the other carries off the fluid. The plate is soon discharged, and then charges in the opposite manner.

Exp. The reason of the more rapid action depends on the greater difference of the electrical state of the point, and the electrified conductor to which it is exposed, and the whole corresponds with the other appearances.

Ph. 209. When the plate is charged, as in *ph.* 206, if the point of the wire on the positive side of the plate be touched by a conductor, the other wire will shew only an illuminated point; but if the negative wire be touched, the other will throw out diverging streams of light.

Exp. The reason of this will be seen from the foregoing.

Ph. 210. If an uninsulated metallic knob be placed an inch and a half from the conductor, so as to receive sparks, a point held at twice that distance will cause the sparks to cease.

Exp. The readiness with which the fluid enters or leaves a point, as before explained, accounts for this effect.

Ph. 211. Sparks are more brilliant when they pass through the air between good conductors, than between bad ones.

Exp. In the first case, the fluid passes more readily and forcibly at once, because of the freedom of motion on the good conductors, and hence arises the denser light.

Ph. 212. If a Leyden jar be rendered slightly damp by breathing into its inside, then if it be strongly charged positively in the inside, and the charging process be continued, luminous streams of light will be seen, which appear to flow from the inner coating, over the uncoated part, to the outer coating: if the inside be charged negatively, the light will still be seen, but will appear to flow from the outer to the inner coating.

Exp. The electric plate being slightly damped, the spontaneous discharge is prevented, (*ph.* 163 and 164); hence the electric fluid, which exceeds the full charge, will pass in diffused streams over this moistened and intermediate surface, occasioning the diffused light; and the apparent direction is that which by the preceding principles ought to be the true direction.

Ph. 213. If a charged jar be placed under a receiver, and the air exhausted, flashes of light will be seen, and will apparently proceed from the positive to the negative side.

Exp. This accords with *ph.* 212, the rarefied air being a partial conductor.

Mechanical Action.

Ph. 214. If a card or quire of paper be placed in the electrical circuit, when a large jar or battery is discharged, a hole will be made through it, and the paper will be protruded both ways, making a bur on the two surfaces at both ends of the aperture.

Exp. The common spark, and much more that which passes in the discharge of an electrical plate, passes through the air in a body, as noticed in *ph.* 63, and 74; now suppose the body of fluid moving along the interrupted discharger from the positive to the negative side and piercing the card, or quire of paper, which, being a non-conductor, resists its direct progress, the fluid will therefore press strongly against the sides of the aperture, while it is forming, and will recoil on those sides, towards the entering point recurving again into the current, as the resistance is overcome at the farther side at which the fluid rushes out; hence a bur will necessarily be made at the entering side as well as at the other.

Ph. 215. If the quire of paper be freely suspended, and the charge sent through it, as before, the same phenomena occur, and yet no motion is communicated to the paper.

Exp. While the aperture is forming, the re-action by the recoil at its sides, towards the entering point, is equal to the action of the body of fluid by which the aperture is formed, hence while the electric fluid is making its way through the interior of the paper, it can produce no motion in the suspended quire, and therefore whatever motion is communicated, must be at its passing the thinnest stratum of the first leaf, which is itself counteracted

by the re-action at leaving the last stratum; hence not only the bur ought to appear on both sides, but also the pendulous body ought to remain motionless.

Ph. 216. If a piece of tin foil be placed between several leaves of paper, and the explosion be sent through it, the tin foil will be indented in opposite directions generally in two places near each other.

Exp. The tin foil is a good conductor, over and through which the electric fluid can readily pass without breaking a hole through it; hence the leaves of paper next the positive wire, while being burred on both sides, produce an indentation on the thin metallic leaf, the fluid flowing freely through the metal, enters the paper on the other side, where it finds least resistance, near the line of its motion, and the elevation of the paper or bur produced on the leaves of paper to the negative side produce another indentation on the tin foil in the opposite direction.

Ph. 217. If there be several leaves of tin foil placed in the circuit between the different leaves of paper, there is a double indentation on each in a similar manner.

Exp. This arises from the same cause and the explanation is similar.

Ph. 218. The greater the number of the leaves of paper between the tin foil, the greater is the indentation.

Exp. The resistance is greater in this case, hence a greater protrusion is made on the paper, and consequently a deeper indentation on the tin foil.

Ph. 219. When the thickness of the paper is very great the tin foil is sometimes perforated.

Exp. The force of the current, and of the protruded paper in this case is evidently sufficient to account for the fact.

Ph. 220. If *ba*, *fig.* 97, be a pointed wire proceeding from the positive side of a battery, and *cd* one connected

with the negative side, GH the section of a card between them: when the battery is discharged, a spark will pass from *a* on that side of the card to *s*, where it will pierce the card to enter the negative wire.

Exp. The atmospherules of the atoms of the air will be condensed about the point *c*, as will be understood by observing the position of the short lines at *b*, *fig.* 67; and the atmospherules of those at *a*, *fig.* 97, will be extended outward, towards *s*, hence the line of easiest passage for the spark will be formed on the positive side *a s* of the card; so that the place of penetration will be near *c*, the point of the negative wire.

Ph. 221. If the experiment, as above, be made with the card in an exhausted receiver, it will be pierced near the middle *t*, and as the air is admitted, so as to render it more and more dense, the place where it enters the card will be between *t* and *s*, and nearer to *s* as the air is more dense.

Exp. When the air is absent the atmospherules of the atoms of the card are most concerned in preparing, or rather directing, the course of the spark, and these extend towards *s* on the lower side and towards *c* on the upper, and most on the lower side from *a* to *t*, and on the upper from *t* to *c*; hence the aperture will be about *t* the middle between *a* and *c*, but as the air is admitted, and becomes denser, the resistance to the passage at *t* is augmented by the atmospherules of the air pressing towards *c* on the upper side, as shewn in the last, hence the effect will be to cause the spark to proceed nearer to *s* before it pierces the card.

Ph. 222. When a powerful electric charge is passed through a slender iron wire, the wire is ignited or dispersed in red hot balls, a greater or less length is burnt, according to the quantity of coated surface, and the height of the charge.

Exp. A very large body of electric fluid, passing rapidly over a very small surface, must partly force its way by displacing a considerable portion of air on every side of its path, by the caloric excited in the air partly, and partly by the caloric contained in the electric fluid, and partly by that excited in the iron by the strong action in so small a space, the effect is produced; and a stronger charge will melt a greater length of wire, because of the greater quantity of fluid, and the greater velocity and compression on the wire.

The various phenomena we have already explained, include the leading facts in common Electricity, those which relate to its chemical actions will be found in the next section of Galvanism; and some relating to atmospheric Electricity in *sect.* ix. A great many others might have been brought forward, but the most general and difficult have been presented to the Reader, and he will now find it easy to explain all the particular cases on the same principles, referring them to their proper heads in this section.

SECTION VIII.

GALVANISM.

Galvanism, or voltaic electricity, which has also been called hydro-electricity, is a branch of science of modern date; it originated from some electrical experiments performed by S. *Galvani*, professor of anatomy at *Bologna;* this philosopher published an account of his discoveries in 1791, and they were repeated, varied, and extended by *Volta*, *Valli*, *Fowler*, *Hombolt*, *Monro*, *Robinson*, and others. Signor *Volta* published an account of his pile constructed of dissimilar metals in contact with each other, and having cloth wetted in salt and water placed between each pair of the metal plates: from a large combination of this kind many important and surprizing facts were discovered. From this time the science was cultivated with great interest, both by the Continental and British philosophers: several additional very important facts respect-

ing the chemical agency of *Volta's* pile were very soon discovered by Messrs. *Nicholson* and *Carlisle,* Sir *H. Davy, Cruikshank,* Dr. *Wollaston,* Dr. *Henry,* &c. &c. Several variations and alterations were made in the form of the apparatus, and a multitude of new results were published to the world in succession: the principal of these are selected, laid before the Reader, and explained in this section.

Contact of Metals.

PH. 1. If a clean smooth plate of zinc be applied to a similar plate of copper, by means of insulating handles, after the separatiou the zinc is found to be electrified positively, and the copper negatively. The like happens in general when dissimilar metals, or various other dissimilar bodies are employed.

Exp. Particles of air, particularly of oxygen, adhere to the surfaces of metals, and the more so as the metals are the more bright and polished, but, according to the laws of affinity, the atoms of oxygen will be most closely attached to the most oxidable metal, and more loosely to the other; and therefore the atmospherules of ethereal matter on the adhering air will be greatest in the latter case, and hence, when the zinc and copper surfaces are brought together, several atoms of oxygen will leave the copper and adhere to the zinc, bringing with them their atmospherules, partly composed of electric fluid, and from their nearer application to the zinc, than that which they had with respect to the copper, will render the zinc

positive, and leave the copper negative, or if the atoms of gas do not actually leave the copper to adhere to the zinc, they will be so far carried towards the zinc, that a portion of their atmospherules will pass over. The same explanation holds in other cases exhibiting the phenomena in a higher or lower degree according to circumstances.

Ph. 2. If a concave plate of copper be pierced with holes, and zinc filings be sifted through, the copper being insulated, the filings will be positive and the sieve negative; if the sieve be zinc and the filings copper, still the zinc will be positive and the copper filings negative.

Exp. This is explained as the preceding phenomenon, but the effect will here be greater, because of the greater surface, and still more on account of the angular points, of the filings.

Excitement of the Electricity.

Ph. 3. AB, *fig.* 68, is an oblong trough divided by partitions into a number of cells (in the figure the front side ABCD is supposed to be removed in order to shew the plates *z*, *c*, &c. and the interior of the cells, which are here represented wider than necessary); c, c_1, c_2 &c. are plates of copper, and z_1 z_2, &c. plates of zinc, in the several cells, the copper plate of one cell being connected with the zinc of the other, by metallic arcs, as a_1, a_2, a_3, &c. the several pairs being arranged in the same order. Now the cells being filled with water, or water acidulated with sulphuric, muriatic, or nitric acid; on examination it is found, that if the cell, in which is the copper of the first

combination, be connected with the ground, the other extremity is electrified in the positive state. When the combinations are very numerous the electrical state is very evident by means of the common pith ball electrometer; with a less number, a more sensible instrument, as the gold leaf electrometer, is requisite to shew the electrical effects; and when there are but 8 or 10 plates of each kind, a multiplier, or condensing electrometer must be employed to exhibit the electrical state.

Exp. It is manifest from the phenomena, that each of the several combinations a_1, a_2, a_3, &c. produces some portion of the effect, since, by increasing the number of plates in the series, the electrical intensity is always increased, other things being the same. Now let the first cell *m* be connected with the earth by a wire *b*, and it is evident the cell will be preserved in its natural state; suppose for a moment, that all the plates except z_1, are copper, then because of its affinity for oxygen, the zinc will soon be coated with a thin surface of oxide; but the oxide is a better electric than the metal, or even than water; it will therefore readily receive and retain the electric fluid from a contiguous conductor (*ph.* 6, *sect.* vii.) and most readily from the best and nearest conductor; also some bodies, as oxygen, on being freed from one combination and entering another, take up ethereal matter: now the zinc is not only in more immediate contact with the oxide, but is a much better conductor than water, and therefore the oxide in forming, or even oxygen coming into contact, will imbibe electric fluid from the surface of the zinc, which it covers, more readily than from the water, and the electric fluid, thus absorbed, will be with facility supplied from the earth by the wire *b* and arc *a*, in contact with *c* the plate of copper, the oxidation proceeds, some portions

of the oxide will be protruded, producing roughness, and asperities on the surface, and from these prominences a quantity of electric matter will be communicated to the cell *n*; moreover some part of the oxide will be detached, and will therefore carry off with it a much greater supply of electric fluid to *n*; also some part of the oxide will be dissolved by the menstruum, and yield the electric matter it had imbibed into the cell *n*; hence this cell is in a higher electrical state than that of *m*; and because the very thin coat of oxide, by which the surface of the zinc is covered, is in a greater degree than water a non-conductor, it will, according to the degree of its non-conducting power, prevent the return of the electric fluid from *n* to *m*, so that it will maintain a given difference in the electrical intensity between the cells *m*, and *n*, and the less oxidable metal *c*, in the cell *n*. Let that difference be called *a*; then the intensity of the cell *m*, being in its natural state, is $=o$, and that of *n*, or rather of the copper in it, is $=a$, and because of the connecting arcs, a_2, a_3, &c. on the supposition z_2, z_3, &c. are copper, the whole of the series from z_1, or c_1, will have the intensity denoted by *a*. Again, let z_2, of the second combination, be zinc, then for the same reasons as stated above, the cell *o* and copper c_2, will maintain the intensity *a* above that of the cell *n*, and the electric fluid derived from *n*, to supply the cell *o* will itself be supplied by a continuation of the same process, *viz.* that of the oxidation of the metal, which is going forward, or of the oxygen which accumulates on it by adhesion, so that the same difference of intensity will still be maintained between *n* and *m*, and *m* will continue neutral; hence the cell *n* will continue to have the intensity *a*, and consequently the intensity of the cell *o*, and copper c_2 will be

$2a$. By the same process of reasoning, it will evidently follow, that the electric intensity of each cell will exceed that of the preceding one, by the same quantity a, and hence the number of combinations being n, the intensity of the last cell will be $n\,a$, that is n times a, and the condition of the apparatus, in respect of the electric state of the cells, will be represented by the series $o, a, 2a, 3a, \ldots na$. Therefore, since the passage of the electricity is from the cell m towards the zinc in n, and similarly throughout the series, it is manifest, from the above and the explanations in electricity, that the zinc end will be positive, and the more so as the number of plates is greater, which agrees with the facts to be explained. It will be readily seen, that a thick coat of oxide adhering firmly to the surface of the zinc, would impede the effects; hence, to produce a maximum in the effects, a certain particular thickness of the coat of oxide is requisite.

PH. 4. If the plates be unconnected with the metallic arcs a_1, a_2, &c., and the plate c be laid flat on a support, and z_1 upon it, and again on this a piece of cloth steeped in the acid solution, then on this cloth another plate of copper c_1 with a zinc plate z_2 and another piece of wet cloth, the combinations being repeated till a pile of any required number be constructed, the same effects occur as above described, and this was the original form of the apparatus contrived by the acute philosopher, Sen. *Volta*, and hence it is called the voltaic pile, and the instrument under its various forms is often denominated the voltaic battery: *fig*. 69 represents a part of such a pile, in which c, is copper, z, zinc, and m, moistened cloth.

Exp. This and other forms of the apparatus depend on the same principles, and are to be explained after the same manner. The first zinc plate receives a coat of

Exp. This brings the apparatus into the condition of *ph.* 3; it is evident that the copper end must be neutral, being connected with the ground, and the rest must have place on account of the same constant electrical difference of intensity being preserved by the continued action of the apparatus.

Ph. 10. Things being as in *ph.* 8, let now the positive end be connected with the ground, it will become neutral, the middle will be negative in the same degree as the negative end was before, and the negative end will be depressed, or rendered more powerfully negative, in an equal degree.

Exp. The preceding explanation taken in the reverse order will apply to this. The given difference being maintained between every two pair of plates, the same difference will remain between the extremes, and the upper cell being lower, all the others are lowered in the same degree by the continued action.

Ph. 11. If the combinations *ph.* 3, consist of plates of copper and iron, the iron being substituted for the zinc, and the cells filled with a solution of sulphur and potash, the copper end is positive, and the iron negative.

Exp. In this arrangement the copper is positive, because it has under these circumstances a greater affinity for sulphur than iron has, and consequently the electric coat of sulphuret, deposited on the copper plate, produces an effect similar to that of the coat of oxygen on the zinc, in *ph.* 3; and hence the explanation is exactly of the same nature, and will be clearly understood from a proper attention to what is there advanced.

Ph. 12. If the voltaic pile, mentioned in *ph.* 4, were constructed of the zinc and wet cloth alone, leaving out the copper plates, it would be inactive.

Exp. In this case the zinc plates are oxidized equally on both sides, and the electricity is supplied from without to the interior of the zinc, and thence equally to the two surfaces; hence the electrical intensity cannot be raised higher in the one plate than in the others. The intervention of the copper plate when used defends one side of the zinc, and supplies the electric fluid to the other side.

Ph. 13. If a piece of metal be taken into each hand, previously moistened with water, or with salt and water, and one metal be dipped into the cell at one extremity of the apparatus, consisting of many combinations, and the other metal be also dipped into the cell at the other extremity, a shock will be experienced, similar to that from an electric battery very slightly charged.

Exp. This will arise for the same reason in the two cases, *viz.* on account of the passage of electric fluid from the positive to the negative pole; the shock is not so violent as a charged electric jar, because of the less intensity; but in this case, there will be a continual action because of the constantly renewed energy.

Ph. 14. When the voltaic battery is charged with water, the shock is exceedingly feeble; but it is greatly increased by adding a little salt to each cell, or by charging the cells with an acid solution.

Exp. In the first case the process of oxidation goes on very slowly, and hence the quantity of electricity transmitted in a short time is small; but when the salt or acid is present in the water, the oxidation goes on rapidly, and a portion of the oxide is speedily deposited in the menstruum; hence a large quantity of electric fluid is quickly supplied, and the shock becomes much stronger, because the quantity of fluid is great, and the same energy is maintained by the rapid oxidation.

Ph. 15. Notwithstanding the great increase of the

shock, when the cells are charged with an acid solution, the electrical indications on the electrometer are not increased, but rather somewhat diminished.

Exp. The electrical indications will depend on a certain and uniform thickness of the coat of oxygen on the surface of the zinc, which is maintained with great constancy, while water alone is in the cells, and the action is slow and regular; but when the acid is present, the oxide is formed and dissolved more or less rapidly: and hence the electric difference of intensity between each pair of plates is diminished rather than increased, so long as the electric fluid discharged by the dissolved oxide, cannot escape from the apparatus, and serves to check the process, but a good conducting connexion increases the activity of the series.

PH. 16. The battery charged with an acid solution continues in action some time, but its power gradually diminishes until it becomes very feeble.

Exp. For the action will continue as long as the process of oxidation continues to advance, and the oxide to be dissolved; but when the liquid is saturated, the chemical action is impeded, and the more completely so, because of the coat of oxide already formed on the surface of the zinc, for when this is increased, and fixed firmly on that surface, it will evidently diminish the power in a very great degree, so that even if a fresh supply of the menstruum be introduced, it will at first act feebly, since it must dissolve a portion of the oxide before it can have access to the metallic surface of the plates.

PH. 17. When the extremities of the voltaic battery are connected by imperfect conductors, the effects are nearly the same, when there are the same number of combinations, whatever is the size of the plates, and the

nature of the interposed fluid, provided it be such as will produce active combinations.

Exp. For the electrical intensity being nearly the same in these different combinations, (*ph.* 6 and 15), and the connecting body is an imperfect conductor, it follows that such conductor will convey the electric fluid from the positive to the negative end of the battery, not so fast as it might be supplied by the action of the apparatus, but in proportion to the electric intensity of the extremities, that is equally in the different batteries, the intensities being equal.

PH. 18. The same things supposed, except that the ends of the battery are connected by very good conductors, as metallic wires, the effects produced by the battery with large plates are very much greater, than those of the other, which contains the same number of small plates.

Exp. For the intensity at the first is the same in both the batteries, and, because of the conducting property of the connecting body, the electricity is instantly carried in both from the positive to the negative end; but the quantity of electric fluid, thus quickly carried from the positive end, is soon supplied in order to maintain the electrical difference *a* of intensity, as shewn in *ph.* 3, and that conveyed to the negative end is carried on through the apparatus, for the same reason, partly because it traverses conductors, but chiefly by the continued and increased action of the apparatus; now the large plates will supply a much greater quantity of the fluid, though there is not a greater intensity, therefore not only will the connecting conductor be supplied at first with a greater quantity of fluid to be transmitted, but on account of this greater quantity, and the more extended action of the large plates, the electrical difference of intensity will be more rapidly

and steadily supplied, and it is constantly supported by the action of the combinations; hence, from the greater current of the fluid, the greater effects will be produced.

Ph. 19. If the number and size of the plates be given, and the ends of the battery be connected by good conductors, the effects become greater when the interposed fluid is more active in oxidizing the zinc plates, but the ratio of increase is affected by the production of vapour.

Exp. This will follow evidently from the foregoing explanations, especially the last, for the electricity is in this case more rapidly liberated from, and consequently supplied to the several plates, and thus, though the intensity be the same, or even diminished, an increased current is produced and continued.

Sch. Hence it appears from the preceding phenomena, that the effects will be greater as the oxidating power of the liquid, the number of plates, their magnitude, and the goodness of the conducting wire, which connects the ends, is greater.

Ph. 20. The more powerful the chemical action of the menstruum on one of the metals, the other remaining the same, the greater in general are the effects of the voltaic battery.

Exp. Because the greater action of the menstruum more speedily liberates the electric fluid, and restores the electrical difference of intensity between the plates.

Ph. 21. When the chemical action is very energetic, its duration is generally transient.

Exp. When the chemical action is strong, the combination of the elements is speedily effected, and when the point of saturation is attained, the production of the electric fluid is arrested.

Mechanical Action, &c. of the Galvanic Battery.

PH. 22. If the pieces of metal held in the hands, as in *ph.* 13, be dry, and the hands also dry, the effect of the battery is scarcely perceptible, unless the series be very extensive.

Exp. The dry skin is nearly as good a non-conductor as the coating of oxide on the zinc plate, and hence it is sufficient to resist the passage of electricity of so low intensity.

PH. 23. When the hands are moistened, as in *ph.* 13, the slight shocks are rapidly repeated, so that the effect seems to be continual.

Exp. This must be the case from the continual restoration of the equilibrium as fast as it is destroyed, the action of the plates and acid solution, which produces the electric difference between the combinations, tends quickly to restore it, when destroyed, so long as the chemical action continues to operate with energy.

PH. 24. When the connexion is formed at one end by the moistened hand, as above, and then made repeatedly at short intervals with the other, the shock is stronger, and more distinct.

Exp. The short intermissions between the entire connection of the extremities gives sufficient time for producing the equilibrium, or electric difference between the plates, to the full extent which the apparatus can maintain.

PH. 25. When the ends of the voltaic apparatus are joined by a very good conductor, as a metallic wire, a constant current of electricity is found to pass along the wire, while the battery is in action.

Exp. The reason of this will be easily collected from the foregoing explanations, considering at the same time the free passage of the electric fluid along the metallic wire.

Ph. 26. If the zinc plates in the apparatus, *ph.* 3, represented in *fig.* 68, be so constructed, that the copper plates be made sufficiently long, and turned round the lower end of the zinc, and extended upwards to face the opposite side of the zinc, but no where to touch it, the effect will be greatly increased, or nearly doubled, as to the quantity of the fluid, but the intensity, as indicated by the electrometer, remains nearly the same. This improvement is due to the penetration and sagacity of Dr. *Wollaston.*

Exp. The electrical intensity is not increased, because the number of plates and the electric difference of intensity between each continues the same, as already explained, When the copper is exposed to one face of the zinc only, the electric fluid, liberated and discharged in the acid solution, tends to diminish the process of oxidation, but this fluid is carried off to the copper from that part of the surface which is near it; hence, on that side the action will be in full operation, while on the opposite side it is very languid. When the copper is made to extend, so as to face both sides, the liberated fluid is carried at once from these surfaces to the copper, and conveyed through the apparatus, the metal being an excellent conductor; hence, the effect is by this means greatly increased.

Ph. 27. The power of several batteries may be combined, by connecting them together by metallic arcs, as for instance, slips of copper; the whole will then act as one large battery, the zinc end of one being in every case connected with the copper end of the other. It is best,

when possible, to make the connecting metal one of the combinations.

Exp. The connecting metal, assisted by the action of the current on it, permits the electric fluid to pass readily from the positive end of one, to the negative of that to which it is connected; and hence, the reason of the united action is seen, and also the reason that it should itself form a galvanic connexion.

Ph. 28. If any of the connected batteries, or even single plates, be arranged in a reverse order, in respect to the rest, the intensity of the action is diminished.

Exp. It will be easily seen, that the tendency of the reversed plates will be to direct the fluid in a course opposite to that of the current, and hence such an arrangement diminishes the effect.

Ph. 29. When an electrical jar or battery is placed in the circuit, so that a wire from the negative end be connected with one side, say the outide of the jar, and a wire from the positive end be brought into connexion with the knob, the jar, especially if it be a very thin one, is instantly charged in a low degree.

Exp. This evidently ought to take place from the passage of the electric fluid through the apparatus, and the charge must be in proportion to the intensity of the electricity; hence it will be but very small, even when the number of plates is considerable.

Ph. 30. The electric jar or battery is charged nearly as well when the interposed fluid is water, as when it consists of acid solutions.

Exp. From the last it appears, that the charge of the jar will depend on the electric intensity of the apparatus; and hence, the reason of this is manifest, since the intensity is as great (*ph.* 15) when charged with water, as when acid is employed.

PH. 31. If any part of the face be made the circuit, a vivid flash of light is perceived at the moment of contact to complete the circuit.

Exp. This will be the natural consequence of the passage of a spark of ethereal matter near the eyes; an appearance somewhat similar is observed, when those parts of the body in the vicinity of the eyes receive a moderate blow.

PH. 32. When from the extremities of a powerful voltaic battery two wires are brought into contact, it is found that at the moment of contact a distinct spark appears, which occurs every time the contact is broken, and renewed again for several successive times.

Exp. The wires being very good conductors, and the apparatus a powerful one, a large quantity of electricity passes at once, and produces the spark with a slight fusion of the wire.

PH. 33. If to each of the wires be attached a piece of well burnt pointed charcoal, and the points be brought into contact, a much more brilliant spark is produced than by the wire alone.

Exp. The electric fluid in leaving the one, and in entering the other charcoal point, radiates much more than at the ends of the wire, which may well arise from the difference of the substances; the charcoal is a good conductor, but not equally so with the metal.

PH. 34. When the apparatus is very powerful, the emission of light may be kept up for a long time, at the charcoal points, in a degree so dazzling as to fatigue the eye with its brightness.

Exp. This will be understood from the preceding explanation, the increased effect arising from the very great quantity of electric fluid transmitted.

PH. 35. The distance at which the spark passes be-

tween the metallic or charcoal points is very small in very dry air. Mr. *Children* found it to be one-fiftieth of an inch with 1250 pairs of plates; with 2000 pairs of four inch plates, the distance, at which the spark occurred, was one-fortieth, or one-thirtieth of an inch.

Exp. The low intensity of even the most powerful voltaic combination known, sufficiently accounts for this circumstance.

Ph. 36. After the charcoal points are intensely heated, they may be gradually withdrawn to the distance of three or four inches, and a stream of light then appears in the form of an ascending arch, broad in the middle, and tapering towards the charcoal.

Exp. The great heat, produced at the points by the powerful action of the battery, prepares the way for the rapid passage of a strong current of electric fluid, and the heat rarefying and expanding the air, particularly above, causes the broad arch-like appearance of light.

Ph. 37. Almost any combustible substance placed at the charcoal points is inflamed.

Exp. The points of the charcoal are ignited when the battery has a moderate power, and hence the combustion is produced.

Ph. 38. Metallic substances in thin leaves, being made the medium of communication between the ends of a powerful battery, burn with great brilliancy. The best way of exhibiting these effects is to suspend the leaf from a wire connected with one extremity of the battery, and to bring it into contact with a metallic plate joined to the opposite extremity.

Exp. Metals are known to be combustible bodies, and as a powerful electric explosion will fuze a wire, so a strong current of electric fluid will render the metal hot, and produce ignition in the leaves.

Ph. 39. If a fine iron wire from one end of a powerful battery be brought into contact with mercury, connected with the other end, there is a vivid combustion both of the wire and quicksilver.

Exp. This is explained in the same manner as the last.

Ph. 40. If a fine iron wire of a moderate length be made the medium of connexion, it is fused into red-hot balls.

Exp. The current of electricity is sufficiently powerful and rapid to produce this effect. (See *ph.* 222, *sect.* vii.)

Ph. 41. The wire is rarely dispersed by the electric current of the voltaic battery, as it is by a charged electrical battery.

Exp. Because in this case, though there is more electricity flowing in the current, it proceeds with less violence.

Ph. 42. If a platina wire be made the medium of connexion between the extremities of a powerful voltaic battery, it may be kept at a red, or even at a white heat, for a considerable length of time.

Exp. The quantity of heat, and force of ethereal matter, which is sufficient to fuse iron, will raise the temperature of the platina, the current operating on the atmospherules of the atoms of the metal, and contiguous air, causes a strong radiation of heat, and the caloric thus dissipated will be supplied along with the electric fluid in the current, rendering the radiation continual, while the action is energetic.

Ph. 43. If a fine platina wire, making a part of the metallic circuit of a voltaic battery, be placed within the receiver of an air pump, the connexion being made, and the power of the battery such, that the wire is brought to a dull red heat, and if now the receiver be exhausted, the wire will attain a white heat; the heat will diminish as

the air is admitted, and the process of exhausting and re-admitting the air may be often repeated with decreasing effects on the wire.

Exp. When the air is rarefied, the electric current is less resisted, and therefore flows more freely and in greater quantity, producing a greater effect of radiation on the wire through which it passes than in dense air.

Ph. 44. Things being as in the last, when the current is passed through different kinds of air of the common density, there is scarcely any difference in the effect.

Exp. The resistance is alike in these cases, and this confirms the preceding explanation.

Decomposition and Transfer.

Ph. 45. When two wires of platina, proceeding from the opposite ends of a voltaic battery, are placed in a vessel of water, with their extremities at a moderate distance, a decomposition of the water ensues, oxygen gas is liberated at the positive wire, or pole, and hydrogen at the negative end.

Exp. According to the preceding explanations, a current of electricity flows from the positive end, through the interval of water, to the negative end. Now this current evidently will be most dense at the extremities of the wires, that is, where it leaves the positive wire and enters the negative one; the particles of water consequently must receive on one side, and transmit the electric fluid on the other side; moreover, the atom of oxygen, in the particle of water, having sixteen times the absolute force

of hydrogen, (*ph.* 25, *sect.* iv. *sch.*), it will much more readily receive the electric fluid than the hydrogen, especially if its radius be less, as is probable from the same *sch.*; should its radius be half that of the spherule of hydrogen, its force at the surface of the spherule will be sixty-four times greater than the force of the hydrogen; hence, the atom of oxygen in the particle of water will be directed towards the positive pole, in consequence of its more readily imbibing or receiving the electric fluid, and therefore the hydrogen must be directed towards the other pole. Again, the particle of water receiving the dense stream of electric fluid from the wire, and this adhering most to the oxygen, will tend to separate it from its two associate atoms of hydrogen; for if it can separate the one of those atoms, much more will it separate the other, which forms a weaker combination, (*ph.* 42, *sect.* vi.) The elements being disunited at the positive pole, the atom of oxygen soon becomes surcharged with the electric fluid, and consequently a portion, which may produce an insensible spark, passes to the contiguous atom of hydrogen, or particle of water, and hence a repulsion is produced between them, (*prop.* 14, *cor.* 9), propelling, because of their situation, the oxygen towards the positive pole, and the hydrogen, or particle of water, towards the negative pole; and in this way the oxygen will reach the positive pole, and, not easily uniting with the metal, will there attain an atmospherule of ethereal matter, and rise in the form of gas. Now each atom of the hydrogen, which was liberated, will adhere to (not combine with) a contiguous atom of oxygen, or to a particle of water; and from what was stated at the commencement of this explanation, it will take its position at that side which is towards the negative pole; and the atom of oxygen, or particle of water, to which it adheres, will receive the

electric fluid of the current till saturated; when this happens, the insensible spark will pass to the contiguous hydrogen, hence the hydrogen is propelled towards the negative end, and the oxygen, or particle of water, towards the positive; the hydrogen now in like manner adheres to another particle of water, or atom of oxygen in the current, nearer the negative pole; and the same process is repeated, by this means it necessarily finds its way to the negative pole, where it is pressed against the wire, and, since it does not easily unite with the metal, it will acquire an ethereal atmospherule, and rise in gas. The electric fluid, entering the wire at the negative end, will there also decompose the particles of water, and for the reasons already assigned, the atoms of oxygen will be propelled successively from the negative to the positive side. Hence, in whatever part of the circuit in the interval of water an atom of oxygen is found, it will advance towards the positive wire; and hydrogen, wherever found, will advance towards the other pole, where they will be respectively liberated.

Obs. This process may be thus illustrated: Let a ball of cork be attached to another of wood, suppose beech, as A and B, *fig.* 21; now if this compound body be put into a gentle current of water, the beech ball B will be thrown into a position facing the stream in respect of the adhering cork A, which is on the side towards which the current runs. Again, suppose that the liquid attaches itself strongly to B, pressing round its sides, this would tend to separate the balls, and if not too firmly joined, it would drive them apart, and if a portion of liquid, at the moment of separation, pass from B to A, or from A to B, evidently they would be repelled in opposite directions, A with the stream, B towards its source. A meeting with another ball like B, or B with one like A, they

would adhere, and take a similar arrangement, and the process would be repeated.

This case in many respects is very different to that of the particle of water, and the electric current; but the analogy may be sufficient to assist the mind in conceiving rightly of the actions above explained.

Ph. 46. If the wire at the positive end be a metal easily oxidized, the oxygen will combine with it, and no gas will be evolved at that pole.

Exp. The action by which the atom of oxygen is carried towards the positive wire, as above explained, tends to press that atom close to the metal, and hence to facilitate the combination, and therefore the wire is oxidized, and the gas does not rise.

Ph. 47. If three or more wires be immersed in the water in a line, with small intervals between them, and the extreme wires be connected with the opposite ends of a voltaic battery, the ends of all the wires which point towards the positive pole liberate hydrogen, and all the other ends separate oxygen.

Exp. The explanation of *ph.* 45 being admitted, this follows as a necessary consequence, for the electric fluid will enter the wires, and pass along them in preference to the water in which they are placed, because the metal is a much better conductor than the water.

Ph. 48. Each of the copper plates in the arrangement, *fig.* 68, (see *ph.* 3), evolves hydrogen, and each of the zinc plates is oxidized, also it is found that each plate of copper gives out the same quantity of hydrogen during the same interval of time, when the combinations are alike.—*Davy.*

Exp. The oxygen is carried to the zinc, and the hydrogen to the copper in each cell, for the reasons already explained in *ph.* 45, the zinc is oxidized, (*ph.* 46), and

each plate gives out the same quantity of gas, because, as explained in *ph.* 3, the difference of the electrical state is the same in each of the different combinations.

Ph. 49. When the voltaic apparatus is placed in a vessel of water, and covered by a receiver, the oxygen of the enclosed air is absorbed by its actions.

Exp. The oxygen contained in the cells of the trough, or moistened cloth of the pile, as well as that which is derived from the decomposition of the water, is carried to the zinc plates, and to the positive wire, according to the manner shewn in *ph.* 45; hence, other oxygen from the air is absorbed by the liquid, and this in its turn is carried to the zinc plates, and the process evidently must continue till the enclosed air is deprived of its oxygen.

Ph. 50. Things being as in the last, and the apparatus charged with water, the action becomes nearly imperceptible, when all the oxygen is absorbed from the enclosed air.

Exp. The oxygen gas contained in the water at the commencement, and that afterwards absorbed from the air, is carried to the several zinc plates, (*ph.* 45 and 48), and uniting with them, yields a portion of electric fluid to be conveyed in the circuit, and hence greatly contributes to increase the effects, not only by the quantity of electricity given out by this oxygen, but also by facilitating the decomposition of the water, so that the coat of oxide is renewed; hence, when the oxygen is consumed, the action of the battery becomes very feeble.

Ph. 51. The arrangement, *fig.* 68, (see *ph.* 3), or other similar ones, if charged with water, is much less efficient in vacuo, and in air which contains no oxygen, than where it is exposed to atmospheric air.

Exp. This accords with the foregoing explanations, and with *ph.* 3, since in this case the coat of oxide is not

formed, separated, and reproduced with sufficient rapidity to supply the current of electric fluid.

Ph. 52. If the apparatus be charged with distilled water, the effects are very feeble, especially the chemical effects.

Exp. This arises from the slow accession of oxygen, and the consequently slow oxidation of the plates, and the small quantity of electric fluid liberated; hence, although an action is produced to exhibit the different electric intensities, the power is so feeble that it cannot generate a dense current of electric fluid to effect the chemical decompositions.

Ph. 53. If the apparatus be charged with dilute nitric acid, it continues active even when in a vacuum, or when surrounded by carbonic acid gas.

Exp. The nitric acid contains a large portion of oxygen, of which some part is loosely combined; this part therefore is easily detached, the metal is oxidized, and the process advances constantly, and this renders the apparatus active.

Ph. 54. If in the series, *fig*. 68, for one of the zinc plates a plate of copper be substituted, that substituted copper plate will be oxidized, and its surface will dissolve in a way similar to that of the zinc.

Exp. Suppose the plate z_3 to be copper instead of zinc, and the rest unaltered. Now, because the electric current advances from z_2 to c_2, there will take place between them a transfer of hydrogen to c_2, and of oxygen to z_2, according to the foregoing explanations, (*ph*. 45 and 48), hence z_2 is oxidized by the close application of oxygen to its surface, and c_2 is not oxidized,

because the oxygen is carried from it, and the hydrogen is propelled to it, and evolved at its surface, (*ph.* 48), therefore c_2 is not dissolved, but conveys the current of electricity to z_3, which we have now supposed to be copper, and thence the current passes to c_3; from this it follows, that between z_3 and c_3, now both copper plates, the electric current still subsists, and oxygen is therefore carried from c_3 towards z_3, since it always meets the current, (*ph.* 45), and hydrogen moves towards c_3, because it goes with the current, (*ph.* 45), hence the atoms of oxygen being pressed against the copper z_3, by the propelling force which produces its motion, it is oxidized, and therefore dissolves in the menstruum; the theory here again perfectly agrees with the fact.

Ph. 55. Some metallic bodies, as silver, which in a common state have no action on water, attract oxygen from it easily, when connected with the positive pole of the voltaic battery.—*Davy's* Chem. Elem. p. 160.

Exp. This agrees with the explanations of *ph.* 45, 48, and 54; for in this case the oxygen is carried that way by the action of the current, and by the repulsion it is pressed against the silver with which it consequently unites.

Ph. 56. Some other metals, as gold, or platina, do not by this means become oxidized.

Exp. The atoms of gold and platina are such as present a great resistance to their union with oxygen, (see *sect.* v and vi.), and hence the atoms of oxygen propelled towards them, and pressed against them, (*ph.* 55), do not unite with the metal, but imbibe atmospherules of ethereal matter sufficient to render them gaseous, and rise, as explained in *ph.* 45, in the form of gas.

PH. 57. Some metals, as zinc and iron, which in common circumstances decompose water slowly, cease to attract oxygen from that fluid, when connected with the negative pole of the battery.—*Davy's* Chem. Elem. p. 160.

Exp. According to *ph.* 45, the oxygen of the water is carried from the bodies at the negative extremity, and the atoms of oxygen in the particles of water near those metals, are turned from them, towards the positive end, (*ph.* 45), hence in every way the oxidation of the metals in these circumstances is prevented.

PH. 58. If any conducting substance, capable of combining with oxygen, be connected with the positive end of the voltaic battery, it will attract oxygen with more energy; but if it be connected with the negative end, it will have its affinity for oxygen diminished.

Exp. This can now present no difficulty; it, as well as the preceding facts, is a necessary result from the explanation of *ph.* 45, since the oxygen is carried from the negative end to the positive, that is, always in a direction opposite to that of the current, it therefore is pressed more to any wire at the positive, and less at the negative end.

PH. 59. The decomposition of water will take place, even when it is in separate vessels, provided that the water in the vessels be connected by a moist fibrous substance, as wetted thread, or asbestos.

Exp. What was said in explanation of *ph.* 45, applies also here, for the oxygen and the hydrogen are conveyed along the moistened thread by the action of the electricity of the current, which passing along from atom to atom, or particle of water, on the thread, produces the repulsion between the hydrogen and oxygen as shewn *ph.* 45, and others.

PH. 60. Most other compounds, besides water, have

their elements separated by the agency of the voltaic battery with greater or less facility. The element which is the best conductor of electricity in most cases is deposited at the negative, and the other at the positive pole.

Exp. The electric fluid, leaving the point of the positive wire in a condensed form, will adhere to the contiguous particles of matter, and uniting more closely with one component part, than with the other, will insinuate itself between them, and cause their separation, as was shewn of water in *ph.* 45, and in the observation, the same or a similar effect will be produced by the electric fluid entering the point of the negative wire. Now, as in respect of the decomposed particle of water, (*ph.* 45), so here in respect of any other separated elements of a compound body, the element which most readily receives and retains the electric fluid, will tend to turn itself towards the current to imbibe the fluid, and the other which most readily transmits it, will of course tend to turn towards the negative end with the stream, (see the *obs.* at *ph.* 45); and when the particle is sufficiently at liberty to move, it will take that position; also, as soon as this state of things is attained, the elements will be repelled from each other towards the respective ends of the battery, according to these positions, that is, the element, which most readily receives, and with most difficulty parts with the electric fluid, will be propelled towards the positive pole, and that which most easily transmits the fluid will find in its course the negative pole as shewn *ph.* 45, of oxygen and hydrogen.

PH. 61. If to an infusion of red cabbage, two or three drops of sulphuric acid be added, and the infusion then be neutralized by cautiously adding a few drops of ammonia till the blue colour appears, and a syphon, inserted and filled with this blue liquid, be placed in the circuit

of the voltaic battery, by means of platina wires proceeding from each end of the liquid in the syphon: gas will be evolved, and in a short time the liquor in the positive leg will become red, and that in the other will be of a green colour.

Exp. The gas is produced and evolved as explained in *ph.* 45, also the acid of the solution, as well as the pure oxygen, will, for reasons stated *ph.* 60, be repelled towards the positive end, and the alkali to the negative end of the syphon, and hence the effects above mentioned will be understood, since the acid turns the solution red, and the alkali turns it green.

Ph. 62. Things being as in the last, reverse the ends of the syphon in the connection; then the liquor will shortly resume its original blue colour at both ends, and after some time, the end which was red will become green, and the other red.

Exp. This will be understood from the last, for the acid and alkali are now carried back, and after the neutralization is thus obtained, the effect is again produced as above, according to the order in the present arrangement.

Ph. 63. If very small portions of acid and alkali be contained in water, they are separated to the different poles of the voltaic battery by its continued action.

Exp. Wherever a particle of acid is found in the water of the circuit, it will be propelled to the positive end of the apparatus, according to the foregoing explanations, and similarly, wherever a particle of alkali is found in the circuit, it will be carried to the negative end.

Ph. 64. If a solution of acetate of lead, muriate of tin, or nitrate of silver, be made part of the circuit by introducing the wires from the ends of the battery into it, to within about four inches of each other; the nega-

tive wire will soon be covered with the metal of the solution, exhibiting a beautiful appearance of the revived metal.

Exp. The metallic salt is decomposed, the acid is conveyed towards the positive, and the oxide to the negative pole, also the oxide is decomposed, and the metal is carried to the negative wire (*ph.* 60), while the oxygen is urged the opposite way, and the particle of metal being pressed against the wire by the repulsive action of the fluid between it and the acid, or water, or oxygen, (*prop.* 14, *cor.* 9, *sect.* ii), it adheres as a coating on its surface, and to its outward surfaces new accessions will be made by the same means. Many other metals are revived in the same way.

Ph. 65. If a portion of any saline compound, such as *Glauber's* salt, be placed with water in two cups of glass, agate, or gold, and the liquid of the cups be connected by moistened asbestos, or cotton, &c., and one cup be connected by a wire to the positive end, and the other to the negative end of the battery, the salt will be decomposed, and the acid and alkali, being separated, will traverse the moistened substance, which connects the cups, so that in a few hours the acid will be found in the positive cup, and the alkali in the other.

Exp. The decomposition takes place as shewn in *ph.* 45 and 60; and the separated elements are in like manner conveyed to the opposite extremities.

Ph. 66. If the compound saline solution be placed in one cup, and distilled water in the other, then if the first cup be made positive, the acid will remain in it, and the separated alkali will pass along the moistened connecting substance into the negative cup, containing the distilled water.

Exp. The same general explanations above given will

hold here, the acid being carried towards the positive wire must remain in the same cup, in which it is liberated, and the alkali is repelled towards the other; for while it adheres to any particle of water, that particle and the adhering alkali will be so situated, that the water will face the positive side, because it more readily imbibes the transmitted electric fluid; hence when a portion of the fluid, or small spark, passes from the particle of water to that of the alkali, a repulsion ensues, (*prop.* 14, *cor.* 9, *sect.* ii), and the alkali is forced towards the negative pole, hence in due time it is found in the negative cup.

Ph. 67. If the cup containing the solution be connected with the negative pole, and the distilled water with the positive one, the alkali will remain in the negative cup, and the acid will pass into that containing the distilled water.

Exp. The reason of this fact is at once seen from a consideration of the two last, for the transfer is effected after a similar manner, the acid taking in the order of the arrangement its position towards the positive pole, while the water, or other substance to which it adheres, faces the negative pole.

Ph. 68. If three cups be connected by moistened cotton, and the saline solution be put into the middle cup, and distilled water into each of the others; also if one of these outer cups be connected with the positive, and the other with the negative pole of a voltaic battery, after a certain time, the acid of the solution will be found in the positive extreme cup, and the alkali in the negative one.

Exp. This necessarily follows from the explanations of the two preceding cases.

In this instance the acid and alkali will propel each other in the opposite directions.

PH. 69. If the vessels themselves be formed of solid saline substances, as sulphate of lime, or sulphate of barytes, and filled with distilled water, a decomposition and transfer of the elements of the salt will still take place, but a considerable time is requisite for this purpose.

Exp. The action of the electric current will effect the separation of the saline particles, especially where the wires touch the cup, the rest will be as before; the circumstances of this case, particularly the solid form of the salt, will evidently render the process more slow and tedious.

PH. 70. Sir *H. Davy*, who has greatly enriched the science of chemistry by his researches and discoveries, filled two conical vessels formed of gold, with a solution of sulphate of potassa, after exposure a sufficient time to a powerful galvanic arrangement, pure potassa was found in the negative cone. The decomposition was quite complete; for the liquid in the negative cup contained no acid and the other no alkali.

Exp. The transfer arises from the cause already explained, and the complete separation of the elements arises from this, that wherever there is a particle of the sulphate left in either of the cups, it will receive the electric fluid from the current, and will hence be transferred and decomposed; and wherever there is a particle of acid it will be propelled towards the positive, and every particle of the alkali towards the negative pole of the battery, therefore, sufficient time being allowed, the decomposition will be complete.

PH. 71. The preceding experiment was repeated on several other neutral salts with this invariable result, *viz.* that the acid was collected in the positive cone, and the alkali in the negative one.

Exp. This agrees with *ph.* 60, and several of those which follow it, whence the reason for the facts here noticed is evident.

Ph. 72. Strong solutions, or those in which the salt bore a considerable proportion to the water, were more rapidly acted upon than weak ones.

Exp. In the case of the stronger solution the particles of the salt must be more closely exposed to the action of the electric current, and hence the effect is more rapid.

Ph. 73. Metallic salts were also decomposed. The acid collecting as before in the positive cone, and the metal sometimes with a little oxide in that which was connected with the negative pole.

Exp. The decomposition and transfer proceed on the same principles as before explained, and when the oxide is not decomposed, it takes its position, while adhering to the acid, towards the negative pole, and hence as well as the metal must be propelled towards that end of the battery: and indeed it is probable that in many cases most of the metal arrives at the negative pole in the state of oxide which is there decomposed.

Ph. 74. In one experiment, in which nitrate of silver was placed in the positive cup, and pure water in the negative one, the whole of the moistened amianthus, which connected the cups, was covered with revived silver.

Exp. The silver, probably in a state of oxide, in its passage towards the negative pole, by adhering to the amianthus, and being easily decomposed, has its oxygen separated, and is prevented from advancing to the negative cup by its close adhesion to the amianthus. The other part is as in several of the preceding phenomena.

Ph. 75. Bodies much more complicated in their com-

position, are also decomposed by the electrical current; thus a slip of glass placed in the negative cone, had soda detached from it, and sustained a loss of weight.

Exp. The agency of a dense current of electric fluid may well be supposed to be capable of producing these effects of decomposition by acting more on one of the elements than on the other according to its nature.

PH. 76. When water is long submitted to the action of galvanic agency, a portion of alkali appears at the negative, and acid at the positive wire; but this is less in quantity as the water is more pure.

Exp. Water, however carefully distilled, contains some portion of neutral salts, and however minute the portions of them, they will be brought into the electric current by their tendency to imbibe and convey that fluid while in contact with water, and hence they will be propelled to one of the poles, and decomposed, and then will the constituents be transferred as before to the respective wires.

PH. 77. Different chemical compounds require for the disunion of their elements, various powers and intensities of the voltaic battery.

Exp. This will arise, partly from the proportionate difficulty of destroying the combination, partly from the quantity of other matter, particularly water, which may be present, and still more from the manner and facility with which the particles receive and transmit the electric fluid. To illustrate the last position, let us suppose that water is more easily decomposed than sulphate of potash by the electric action, yet being mixed, if the particle of salt adhering to one of water so receive the electric fluid that it shall be turned *towards* the current or positive pole, while the particle of water consequently faces the negative wire, the repulsion which takes place between them, when the fluid passes from the one to the other,

will propel the water towards the negative, and the salt towards the positive pole, where it will be decomposed in preference to the water. But at the negative wire, we should in this case expect the water to be resolved into its elements.

PH. 78. It sometimes happens, that both a salt, and the water in which it is dissolved, are decomposed at the same time, and their elements transmitted as in the preceding cases; and the decomposition of the one or the other will prevail according to their relative proportions in the mixture.

Exp. The reason of this will appear from *ph.* 72, and the illustration just given above.

PH. 79. The several chemical decompositions, produced by galvanic arrangements, may be effected by common electricity, when the current is directed in a stream sufficiently fine, and dense. This was first successfully exhibited by Dr. *Wollaston.*

Exp. The current of electricity is here under circumstances somewhat similar to that in the voltaic battery, and hence ought to produce like effects.

PH. 80. The elements of bodies may also be transmitted by means of the electric current through substances for which they have a strong attraction, without combining, as they would under common circumstances.

Exp. The substance transferred is enveloped in an extensive atmospherule of electric fluid, as are also the other substances, which are in the course of the electric current; hence while the transfer is effected, the chemical union is prevented by the interposed electric fluid, which is concerned in conveying the separated elements through the menstruum, and the action itself also which conveys the elements, tends to keep them asunder, therefore it cannot be expected that under these circumstances there

should be an union of the elements, however strong their chemical affinities.

PH. 81. Let sulphate of potash be placed in the negative cup *n*, *fig.* 70, a solution of ammonia in *m*, the middle cup, and distilled water in *p*, the positive cup, also let the liquids in the cups be connected by moistened cotton, and the circuit completed by the wires from *p* and *n*. The sulphate will be decomposed in the cup *n*, and the sulphuric acid will pass along the moistened cotton, into the solution, contained in *m*, and thence to *p*, without uniting with the ammonia for which it has a very strong attraction.

Exp. The acid will pass to the cup *p*, as shewn in *ph.* 45, 60, and 80, and being involved in an atmospherule of electric fluid, while it traverses the line of connexion, and is repelled from particle to particle, (*ph.* 80), it is prevented from uniting with the ammonia while making its way through the solution, the action between the acid and ammonia tending to favour their continuance apart.

PH. 82. If an acid be substituted for the ammonia in *m*, *fig.* 70, the sulphate of potassa placed in *p*, and the distilled water in the negative cup *n*, the sulphate will still be decomposed, and the potassa will traverse the line of connexion, passing through the acid in *m*, without entering into combination with it; notwithstanding there is a very strong affinity between the acid and potassa.

Exp. The potassa is transferred as shewn before, and is prevented from uniting with the acid for the reasons assigned in *ph.* 80 and 81, as is very manifest. So far from uniting, the acid will tend towards the positive pole, while the potassa advances the other way, so that instead of uniting they tend to separate.

PH. 83. In some cases the atom or particle which would pass through the middle cup *m*, *fig.* 70, if it were filled

with water, or certain other liquids, will not pass when it is filled with some particular solutions; this happens generally when the solution in the middle cup forms an insoluble compound with that which is to be transmitted; thus sulphuric acid will not pass through a solution of barytes.

Exp. It is not to be expected that the atmospherule of electric fluid, formed on the surface of the passing atom or particle, combined even with the action between them, will in all cases be sufficient to defend it from the strong affinity of the substance through which it has to pass; thus the powerful affinity between sulphuric acid and barytes arrests the motion of the acid in the middle cup, and forms a heavy insoluble compound, which is not conveyed to the next cup.

Ph. 84. Take a resinous plate about half an inch thick, and containing about eighteen square inches of surface, draw the knob of a small Leyden bottle, charged with negative electricity, over one part of its surface, and the knob of a similar bottle charged with positive electricity, over another part of its surface. Place the plate vertically, and project towards it from a spring powder puff, a mixture of red lead and flower of sulphur. The mixed powder will be separated by the different electricities on the surface of the resinous plate. The red lead will adhere to the part touched by the negative bottle, and the flowers of sulphur to the part touched by the positive bottle. The figures they form are very curious, and always of different characters, they may be diversified in a very pleasing manner by describing letters or other figures with the knobs of the electrified bottles, or by communicating electricity to the resinous surface by conductors of any required form. *Singer's* Elect. p. 356. This fact was first shewn by Professor *Lichtenberg*.

Exp. One of the lines drawn on the resinous plate is charged with positive electricity, and the other is rendered negative by the action of the knob drawn over it, as is evident from *section* vii; hence there is a tendency of the electric fluid to pass from the positive to the negative line, and the atmospherules of the air extend in direction from the positive line and towards the negative one. Now when the mixed powder is projected on the resinous surface, it serves to promote the passage of the electric fluid in the way in which it tends to move; *viz.* from the positive line, and towards that which is negative; and because the sulphur retains the electric fluid more firmly than the red lead, and the lead more readily transmits it, the sulphur ought to be carried towards the positive line, and the lead towards the other, (*ph.* 60 and following), by the repulsion produced between the particles, (*prop.* 14, *cor.* 9). Hence the powders are separated, and arranged variously, according to the position in which the lines are drawn on the plate.

Ph. 85. If powdered resin be substituted for the sulphur in the last experiment, it will advance towards the positive line, and the red lead still towards the negative one; and several other mixed powders may in like manner be separated.

Exp. This will be perfectly understood from a due consideration of the preceding, the explanations being similar.

Ph. 86. If the wires of the voltaic apparatus be immersed into a strong solution of sulpharic, or of phosphoric acid, the oxygen will be separated at the positive surface, and the sulphur or phosphorous at the negative surface.

Exp. This is a particular case agreeing in its general character with several of the foregoing ones, and it presents no difficulty.

Ph. 87. When a solution of muriatic acid, which is a compound of chlorine and hydrogen, is acted on, as in the former cases, the chlorine is separated at the positive, and the hydrogen at the negative wire.

Exp. This agrees also with the other results, especially when it is considered that chlorine is thirty-six times more powerful than hydrogen, and hence will be readily presented towards the positive pole.

Ph. 88. The results, mentioned in the various instances of the transfer of bodies to the two poles of the battery, are constant and invariable: the bodies which in one instance are propelled to either pole, are always from the same combinations carried to the same pole.

Exp. If the electric current, passing the different particles of matter in its course, have the effect of arranging those particles, whether combined, or only adhering together, in any particular position in respect of the current, it will always evidently have the same tendency to produce the same order in the disposition of the same combined or adhering particles or atoms; and hence, when the electric fluid passes from the one to the other, repelling them different ways, the motions of any particles will be always in one constant direction, whether to the positive or the negative pole.

Ph. 89. The transfer of elements is effected even in opposition to gravity; for if the moistened cotton, or amianthus, connecting the two cups, be made to ascend considerably from the one liquid to the top of the cup and down into the other, the effect is still produced.

Exp. The effect of the repulsion, between the two particles, by the action of the electric fluid, must evidently be far superior to the action of gravity on the same particles; and hence the effect is still produced.

Ph. 90. Mr. *Porrett* contrived to divide a glass vessel,

vertically, by a piece of moistened bladder, so as to form in it two cells, either of which would hold water without suffering it to run into the other. Having filled one of these cells with water, and put also a few drops into the other, he made the connexion by joining the filled cell to the positive pole, and the other to the negative one.

The decomposition of the water took place as usual, and besides that, the water found its way through the bladder, while under the galvanic influence, so that in about half an hour the water was at a level in the two cells, and the process continued, so that at the close of the experiment the water had risen in the negative cell ¼ of an inch above the other. It is plain that in the latter part of the process, the water is made not only to penetrate the bladder, but also to effect its passage through it, in opposition to the force of gravity.

Exp. The repulsion between an atom of oxygen and a particle of water, occasioned by the electric fluid, must be very much greater than that which is produced between the atom of hydrogen and water, because the atom of oxygen is much more energetic than the atom of hydrogen, probably its force at the surface of the spherule is sixty-four times greater, (see *ph.* 45), and when the electric fluid passes between water and hydrogen, it leaves the weakest side of the particle of water, which (*ph.* 45) is situated towards the negative wire, and consequently the action between the particle of water, and atom of hydrogen, is comparatively small, and the water is urged but a little way towards the positive pole, but the current, passing from the oxygen to the water, meets the most powerful side of that particle, therefore the electric fluid will pass in a larger spark, and with greater force; hence, while the oxygen is propelled towards the positive pole, the particles of water will be forced very powerfuly to-

wards the negative one, and the force of its action at the bladder, with that of the electric fluid, will open its way through that thin membrane, and that even in opposition to gravity within certain limits.—See *Thompson's* Annals, vol. iii. p. 32.

Obs. This phenomenon elucidates the preceding explanations, and exhibits the principles on which they are founded. When water is decomposed, the water itself, as well as the separated hydrogen, is carried towards the negative pole; but without some such contrivance as that which was devised by Mr. *Porrett*, it soon finds its level.

Ph. 91. If a few globules of mercury be placed in a vessel containing water impregnated with a small quantity of saline matter, and the wires from a battery of about 1C00 double plates be introduced into the vessel, opposite to each other, so as to reach the bottom; then, if the battery be but moderately charged, the mercury will be violently agitated, each globule will become elongated towards the positive pole, but the opposite side will retain its position, and its curvilinear outline; under these circumstances oxide is given off at the positive spherical surface of the mercury, but no hydrogen at the elongated negative surface.

Exp. The atoms of oxygen, which are propelled towards the positive pole, are, as in former cases, pressed against the mercury on its positive side, *viz.* that which faces the negative wire, and which preserves its rotundity, and this action of the oxygen tends to prevent the motion of the mercury towards the negative wire; also, when the atom of oxide is formed, it is propelled towards the negative wire by the electric current as before shewn, and the mercury is consequently acted on in the opposite direction; hence this action also tends to preserve the figure of the positive side of the globule. Hydrogen not being liber-

ated at the negative end of the mercury, shews that it is carried through the water, in preference to its being discharged at the surface of the mercury, also the particles of water, and those of the saline matter, with the atoms of hydrogen, receiving the electric fluid around the globule laterally, where also probably some particles of oxide are formed, repulsions between them and the mercury of the globule will occur at its sides near its negative end, and it is evident that all these actions will tend to protrude the negative end of the globule towards the positive wire.

Ph. 92. Things being as in the last phenomenon, so long as no hydrogen is liberated from the negative end of the mercury, it is in continued agitation, and is rapidly extended.

Exp. The innumerable and continually repeated impulses laterally made around the globule, towards the elongated part, as noticed above, (*ph.* 91), will produce the agitation, and the extension of the negative end of the globule.

Ph. 93. Things being as in the two last, if more saline matter be added to the water, or if the charge of the battery be increased, hydrogen will be given off from the negative ends of the globules, and they will then become stationary.

Exp. In the one case, the presence of a greater quantity of saline particles, and in the other the greater energy of the battery may tend to prevent the passage of the hydrogen by the sides of the globule, and to direct it more immediately on the metal, and under these circumstances it must be liberated there, as it usually is at the end of a wire, and when this happens there must be a repulsion between the hydrogen and the mercury at the moment of its evolution at the negative end, and this is sufficient to prevent its elongation, and to preserve its

figure, and this, with the action of the oxygen at the other side, keeps it stationary. For the facts of the three last phenomena we are indebted to Sir *H. Davy*. See his Elements, p. 172.

Ph. 94. When the wires proceeding from the opposite ends of a voltaic arrangement, are armed with charcoal points, and these are brought nearly together, so as to shew the electric light, and the luminous arch, (*ph.* 36), a vivid spot of white light is always seen on the negative point, and diverging rays from the positive point.

Exp. This agrees with the appearances of the light in common electricity, when entering and leaving a point, (see *ph.* 205, *sect.* vii), and the reason of the effect is similar in the two cases, so that the explanation there given will apply in this instance.

Ph. 95. When the wires are placed in a vessel of water, so that it is decomposed, the nearer the wires are together, the more gas will be evolved, provided the wires are not brought into contact.

Exp. When the wires are nearer together, the current has to traverse a shorter space of the imperfect conductor, hence it will act with greater energy: also the elements have to be propelled through a shorter line, and hence the effect will be more rapid.

Ph. 96. In most cases when the water is saturated with some salt, more gas is evolved than when it contains a less quantity.

Exp. The salt renders the solution a better conductor, if while it is decomposed it yields no obstacle to the accession of the electric fluid to the particles of water, it will not prevent its decomposition at the wires, and many particles of water will be decomposed at the passing of the fluid between the particles of salt and those of the water.

Ph. 97. When the wires are inserted into a vessel of water, the apparatus being in uniform action, the evolution of gas at the wires, does not instantly take place to its regular amount, but requires a short time, more or less according to the distance of the wires, and other circumstances, to attain its full effect.

Exp. This naturally arises from the distance, through which some portion of the gases has to be propelled, and is exactly what ought to happen according to the explanations we have already given of the transfer of elements.

Ph. 98. Nitric acid acts strongly on copper, so that if the end of a copper wire be put into dilute nitric acid, it will be dissolved rapidly, but if the other end be connected with the negative end of the battery, and the liquid with the positive end, the wire is scarcely acted on at all.

Exp. Agreeably to the several explanations already given, the acid is propelled from the negative wire towards the opposite wire, and hence the combination is prevented.

Ph. 99. Connect a solution of sulphate of copper with the positive end of the battery. Immerse a slip of silver into the solution for any length of time, it is not acted on by the liquid, but if now it be connected with the negative end of the battery it will soon be coated with copper.

Exp. The sulphate of copper is decomposed, and the atoms of copper are carried from the silver in the first case, but are propelled closely against the silver when connected with the negative end, as in the former cases, and hence the silver now receives a coating of copper in virtue of this action.

Ph. 100. Take four tubes bent as in *fig.* 72, each about one fourth of an inch in diameter and 5 or 6 inches long; fill them with a blue infusion of red cabbage leaves, which has been rendered slightly acid and neutralized, connect them with each other by three arcs of moistened cotton,

and their extreme branches with the opposite ends of the voltaic battery by platina wire. When the action of the battery has been continued a due time, all the liquid in the two syphons nearest to the positive pole will be changed from blue to red, and all that which is in the two others to a green colour.

Exp. The acid of the blue liquor is propelled through the liquid and wet cotton towards the positive end of the battery, and the alkali towards the negative end as before explained; therefore the half of the liquid towards the positive side becomes red by the presence of acid, and the other half green by means of the alkali.

Ph. 101. Repeat the former experiment afresh with the simple variation of substituting three platina arcs to connect the syphons instead of those of the moistened cotton, and it will be found in a certain time that the liquid, in the leg of each syphon which is towards the positive pole, is red, and that the other four legs which face the negative pole will be green.

Exp. In this case the alkali in like manner, and for the same reasons as before, is carried towards the negative pole in each syphon, but when in any syphon it reaches the platina wire the metallic arc more readily receives and conveys the electric fluid than the particle of alkali; hence the fluid leaves the alkali at the extremity of the platina wire. In like manner the acid arriving at the wire is not propelled with force sufficient to carry it along the metal on account of its superior conducting power, and the great quantity of fluid it communicates at once to the particle of acid, hence the one half of the liquid of each syphon will be red, and the other half green in the order mentioned.

Ph. 102. Take a tube about two feet long and half an inch in diameter, and place in it by means of pieces of

cork, a series of wires, each about an inch and a half or two inches long, leaving a distance of about an inch between the several wires. Let the tube be filled with a solution of lead, and well corked, a wire passing through each of the two extreme corks to connect it with the ends of the voltaic battery; in a short time the negative end of all the wires will be covered with a vegetation of metallic lead.

Exp. The lead separated from the oxide, or the oxide itself, is carried as usual towards the negative pole, and, when it arrives at one of the wires, it is propelled close to that wire, which freely receiving the electric fluid and transmitting it, leaves the lead adhering to the wire. The new accessions of lead in like manner are deposited on, and adhere to that which already has been fixed, and hence a sort of vegetation proceeds, in the mean time the electric current flowing along the wire, decomposes the oxide of lead in passing the liquid at the end of the other wires, and thus all the negative poles of the wires will exhibit the vegetation of lead.

PH. 103. By the agency of galvanism the fixed alkalies, and alkaline earths have been decomposed: Sir *H. Davy* first discovered the compound nature of these bodies, and shewed that they consist of a metallic base and oxygen. Let a plate of silver or platina be connected with the negative side of the voltaic battery, on which place a thin piece of pure potassa or soda: a platina or silver wire, proceeding from the positive end, is then to be brought into contact with the upper surface of the akali, it fuses at the point of contact, and metallic globules of potassium, or sodium shortly appear at the negative surface.

Exp. These effects are produced on the same principles as the decompositions already explained, the electric fluid adheres powerfully to the oxygen, and hence separates

the metallic base, which as usual is propelled towards the negative pole, while the oxygen takes the contrary direction.

Ph. 104. When different fluids are employed to excite the voltaic apparatus, that which produces a more powerful action is generally more transient in its duration.

Exp. In the case of a more powerful action, the fluid is more speedily saturated by the oxidation of the metal, after this saturation is nearly attained, the action is feeble, and the coat of oxide on the zinc soon becomes sufficiently thick to prevent the progress of the electric current, and consequently the action ceases.

Ph. 105. Water with the addition of about the five hundredth part of muriatic acid produces a gentle action, which continues for a considerable time: but when the acid is increased to about a twentieth part, the action becomes powerful, but comparatively it is of short duration.

Exp. In the first case the oxidation of the zinc is very slow, and hence a comparatively small quantity of electric fluid is evolved at each place, also it is long before the coat of oxide is too thick for admitting the electric current; but in the second case the action more rapidly dissolves the zinc, and more electricity is evolved, so that the galvanic action is much stronger, but as the liquid approaches towards saturation, the action becomes more feeble, and the greater quantity of oxide adhering to the zinc soon intercepts the current.

Ph. 106. If the several pairs of plates, composing a battery, as represented in *fig.* 68, be connected on the outside of the parts in contact with the acid, by a metallic rod or wire touching the several metallic arcs, the effects of the apparatus will be nearly annihilated: but if a continued metallic communication be made by placing a piece of metal between the zinc and copper in every cell within

the menstruum, the effects will be diminished only in a small degree.

Exp. In the first case, the difference of the electrical intensity between every two plates is equalized by the metallic connexion without. There being nothing to prevent the electric fluid produced by the oxidation of the zinc, and carried to the copper, from returning by the connecting wire to supply the zinc again: in fact, the apparatus becomes a collection of independent galvanic circles, the effect of each terminating in itself. But, in the second case, the developement of the electric fluid at the zinc surface, and its motion towards the copper, produced by the action of the apparatus as already explained, will prevent the return of the fluid by the connecting metal, and as there is no conducting metallic connexion without the sphere of immediate action, the effects are but little diminished.

Ph. 107. Sir *H. Davy* arranged in the usual order forty metallic arcs, of which one leg in each was zinc, and the other silver, in a series of glasses filled with a solution of muriate of ammonia, rendered slightly acid by muriatic acid: whilst the extreme parts remained unconnected by a metallic arc, no gas was disengaged from the silver, and the zinc was scarcely acted upon: but when the connexion was made, all the zinc wires were dissolved more rapidly, and hydrogen was disengaged from every silver wire.

Exp. While the ends remain unconnected, as soon as the electric difference is attained between every pair in the series, the action is nearly suspended; only so much continuing as is requisite to supply the waste of the small portion of fluid arising from the tendency to equilibrium, this state of things being attained, it is clearly manifest that the electric fluid cannot advance, or move from the

zinc in any glass to the silver, because the entire difference of intensity, which the metals are capable of sustaining, is already produced; but when the extremes are connected by a wire, the electric fluid flows along it from the zinc end to that of the silver, because the zinc end is in a positive, and the silver end in a negative electrical state; hence, the fluid flows along the silver leg of the first arc to that of the zinc, in consequence of this water is decomposed as usual, the oxygen is carried to the zinc forming the oxide, and the hydrogen to the silver, where it escapes in the form of gas; hence the reason of these effects is plain and evident.

Ph. 108. When a voltaic pile, constructed according to the directions in *ph.* 4, is placed under a receiver, as in *ph.* 49, and its extremities are connected for some days by a wire, remarkable alterations will be produced on its own elements. If the pile be raised according to the order in *fig.* 69, *vis.* copper, zinc, wet cloth; copper, zinc, &c.; it happens invariably, that particles detached from the several inferior zinc plates are carried through the wet cloth, and adhere to the copper plates next above them; also particles of each copper plate are detached and carried to the zinc plate next above it in order. Sometimes, instead of metallic zinc, the oxide of zinc is attached to the copper plate; and in some instances the zinc so unites with the copper as to form brass.

Exp. When the extremities of the pile are connected by the wire, there is a circulation of the electric fluid throughout the apparatus as before shewn, from the lower to the upper end, and down the wire: the upper surfaces of the zinc plates are oxidized by the oxygen, which is absorbed, till that is expended, and partly by that which is abstracted from the water; the continued action successively detaches portions of the oxide from this surface,

in place of which a new portion is formed, keeping up the process which maintains the difference in the electrical intensity of the plates: now the detached oxide is propelled from the zinc towards the copper, while the acid of the wet cloth is propelled towards the zinc, hence this oxide is carried through the wet cloth to the next higher copper surface to which it becomes attached, when the action is but moderate; if the action be stronger, the oxide is decomposed at the copper surface, in which case the metallic zinc is propelled against the copper, and the oxygen towards the zinc, so that it returns back again through the wet cloth to the zinc, and contributes to renew and continue the action: when the power of the machine is still stronger, the metallic zinc is so forcibly pressed against the copper as to produce a combination with it, and form brass, the compound of these metals. Again, the oxygen which has access between the copper and zinc plates, whose surfaces are contiguous, is, as shewn before, propelled towards the copper, since here the current proceeds from it to the zinc, hence an oxide of copper forms on the upper side of the copper plate, and this oxide is by the nature of the action detached, and carried to the zinc, where being decomposed, as in other cases, the oxygen is propelled back once more to the copper, and forms a new portion of oxide. This process evidently must advance with decreasing energy, and the whole agrees with the explanations already given of the operation of the voltaic pile, and tends to confirm the truth of the conclusions.

PH. 109. If the order of the series in the pile be reversed, so that the plates marked *z*, in *fig.* 69, may be copper, and those marked *c*, zinc, the phenomena will be the same, but exhibited in a reverse order, the atoms of zinc descending through the wet cloth to the copper,

and the copper going, as above explained, to the lower zinc.

Exp. The explanation is the same as in the last, since relatively the phenomena are the same.

Ph. 110. When the extremities of the pile are not connected by a good conductor, these transmissions of the metals do not occur.

Exp. Because in this case the circulation, and consequently the current of the electric fluid, by which the transfer is effected, has no place.

Ph. 111. After the oxide of zinc, or the revived zinc has attached itself to the copper, so as to cover its surface, the action ceases altogether.

Exp. The tendency of the whole action is to attain a state of equilibrium, and balance of the forces exerted in every case of the exposure of bodies to each other: so here when the copper becomes covered with zinc, and oxide of zinc, surfaces of the same kind are exposed, and the actions are suspended, for where no chemical action is produced, no electrical current can be maintained, as is evident from what has been advanced on this subject.

Ph. 112. These re-actions of the pile on its own elements are much more sensible when the plates are of small dimensions than when they are large.

Exp. In small plates the electrical intensity is equally strong as in large ones, and hence the chemical decomposition takes place equally, as far as that alone is concerned: but the interior part of the large plates is much more defended from the air, also the electric fluid tends to pass at the exterior surfaces, (*ph.* 28, *sect.* vii); hence the small plates are more liable than large ones to receive the actions above noticed.

Obs. This and the four preceding phenomena are taken from *Biot's* Traité de Phy. vol. ii. p. 528, and following.

Actions of Single Galvanic Circles.

PH. 113. Single galvanic circles produce remarkable effects, a few of which shall be noticed. "If a piece of zinc, and a piece of silver have each one extremity immersed in the same vessel, containing sulphuric or muriatic acid, diluted with a large quantity of water, the zinc is dissolved, and yields hydrogen gas by the decomposition of the water: the silver not being acted upon has no power of decomposing water, but whenever the zinc and silver are made to touch at their upper ends, or any metallic communication is made between them, hydrogen gas is also formed (evolved) at the surface of the silver." —Dr. *Wollaston.*

Exp. The first part is a case of chemical affinity, the solution is not capable of acting on the silver in common circumstances, hence no gas is evolved from it: but the zinc attracts oxygen from the water, and its other element hydrogen is given out. Now as the oxide forms, it absorbs a portion of electric fluid from the zinc, so that its interior parts, and that portion of it which is out of the liquid, yielding to the coat of oxide a small quantity of the electric fluid, is in a negative state in respect of the liquid; and the coat of oxide, on account of its worse conducting property, prevents the return from the liquid to a certain degree of intensity, as before shewn in several places, so that the equilibrium cannot be restored that way: but when the silver and zinc are brought into contact at their upper extremities, or are there connected by metal, the electric fluid passes along the silver to the interior of the zinc to restore the electric equilibrium,

completing a galvanic circuit; this increases the oxidation of the zinc, which before was going on; for the passing electric fluid propels the oxygen towards the zinc, and the hydrogen towards the silver. Hence, by the continued oxidation of the surface of the zinc, and the solution of the oxide, there are new calls for the electric fluid to pass to the interior of the zinc, in order to supply the newly formed oxide at the surface, this finds its way continually by the silver, so that a constant current is kept up, as long as the process of oxidation is prolonged; now this current as usual propels the hydrogen in its own direction, while the oxygen is thrown the opposite way, and therefore when the communication is made, hydrogen is evolved at the silver wire.

PH. 114. In the preceding experiment, after the contact is made, less hydrogen is given out at the zinc wire.—*Singer's* Elect. p. 361.

Exp. This is the necessary consequence of the contact, because a large portion of the hydrogen set free at the zinc surface is propelled to the silver, as shewn in the last, but the small quantity of electricity in circulation is not sufficient to convey all the hydrogen to the silver, hence some portion of it is still evolved at the zinc surface.

PH. 115. Any other metal besides zinc, which, by the assistance of the acid employed, is capable of decomposing water, will succeed equally, if the other wire consist of a metal on which the acid has no effect.

Exp. This depends on the same principles as *ph.* 113, and is explained in the same manner.

PH. 116. "If zinc, iron, or copper, be employed with gold in dilute nitric acid, nitrous gas is formed, in the same manner and under the same circumstances, as the hydrogen gas in the former experiment," (*ph.* 113).

Exp. This will be understood from *ph.* 113, since the cases are similar, the nitric acid being here decomposed instead of the water in that instance.

PH. 117. "If the solution contain copper, it will be precipitated by a piece of iron and appear on its surface. Upon silver merely immersed in the same solution, no such effect is produced; but as soon as the two metals are brought into contact, the silver receives a coating of copper." This, and *ph.* 113 and 116, are taken from Dr. *Wollaston's* paper, *Nicholson's* Journal 4to. vol. v. p. 337 and 338.

Exp. The electric circuit is here produced, as in *ph.* 114, but it is the oxide of copper that is decomposed, and hence the copper instead of hydrogen is propelled, and deposited on the silver, and the power is not sufficient to convey all the copper to the negative pole, i. e. to the silver, hence some of the copper is still deposited on the iron.

PH. 118. Fill two glasses with a solution of copper, place a zinc wire in one, and a silver wire in the other, and twist the wires together at the top. The zinc will immediately attract copper from the solution, but no copper adheres to the silver.

Exp. The liquid being in two separate glasses there is no conducting communication from the zinc to the silver in the liquid, hence the electric current is not complete as in the preceding phenomena; since there is no liquid connection from the solution in which the zinc is placed, to that which contains the silver, and hence, notwithstanding the connection at the top, the silver must remain unaffected.

PH. 119. Things being as in the last, connect the liquids in the glasses by a platina or gold wire. It will still be found that the copper is not precipitated on the silver.

Exp. The intensity of the electricity is so low as not to be capable of affecting a delicate electrometer, and in this case the quantity is also exceedingly small, hence the gold or platina wire in its natural state (that is, not rendered negative) is incapable of transmitting so feeble a charge of electricity, and since these metals are not acted on by the acid of the solution, the current of electricity cannot exist, and for this reason as before the silver is not affected.

Ph. 120. Instead of the platina or gold arc substitute one of any oxidable metal, suppose iron, and the silver will soon be coated over with copper.

Exp. The iron is acted on by the acid of the solution, had it been the only arc of connection both its ends would have been acted on alike; but now, because there is a tendency of electricity to pass from the zinc in the one glass, and to the silver in the other, the oxygen will tend to pass from the iron at that end, which is in the glass containing the zinc, and towards it at the other end; hence the end of the iron wire in the glass containing the silver will be more oxidized than in the other glass, the end next to the zinc is therefore rendered negative, and consequently a feeble current of electric fluid is carried to the glass containing the silver, and the circulation now being completed, the effect, as in *ph.* 113 or 117, is produced.

Ph. 121. Fill one of the glasses above mentioned with a solution of silver, and the other with dilute muriatic acid; place a piece of platina in the solution of silver; and zinc in the dilute acid; and let the metals be connected at the top. The zinc is dissolved but no silver is deposited on the platina, and the same will still continue, if the glasses be connected by another arc of gold or platina.

Exp. The electric current is incomplete in both instances, since there is no connection in the first case, and in the second it is not effectual, because the acid cannot act on the gold and platina arcs, and of themselves they are insulators to electricity of so low intensity.

Ph. 122. If any other metal, which the solution of silver can act upon, as a silver wire, be taken for the secondary arc, instead of the gold or platina, crystals of metallic silver will be deposited on the platina of the compound arc.

Exp. The solution of the silver is favoured by the tendency of the electric fluid to circulate, in consequence of the actions already produced, and the oxidation of the wire in the solution of silver renders the other end, which is in the dilute acid, negative; hence the electric fluid circulates freely, and of course the silver is as usual carried with the current, and consequently applied to the platina.

Ph. 123. If the two glasses either in *ph.* 118, or 121, be connected by moist cotton, or asbestos, the deposition will be made on the silver in the first case, and on the platina in the second.

Exp. This connection forms a liquid medium the whole way between the wires, and hence the effect is nearly the same as if the compound arc had been in one vessel.

Ph. 124. The chemical action evinced when the glasses are connected by some moistened substance, as in the last case, is slower in proportion as the moistened conductor is increased in length.

Exp. As the distance between the metallic conductors is increased by the liquid, or moisture, the power of transmitting the effect will be diminished, for the atmospherules of the liquid will be less affected at a greater distance from the seat of action.

Ph. 125. The arrangement of a simple voltaic combina-

tion, by Mr. *Sylvester*, is represented by *fig*. 71. It consists of a tall glass jar filled with dilute muriatic acid. Through a cork placed in the neck of this jar two wires are inserted: the one a short straight wire of zinc, the other a long bent wire, of platina or silver: by turning this last round, its upper end may be brought in contact with the zinc, or separated from it at pleasure. When they are separate, the zinc only is acted on, but as soon as they are brought into contact, the platina or silver becomes covered with bubbles of gas, which appear soonest, and are evolved in the greatest quantity from the point S, and the part C; which are those separated by the least stratum of fluid from the zinc wire.

Exp. The several circumstances here mentioned follow as a natural consequence, as is seen, from what has already been advanced on these subjects: the shorter the distance between the points of action, the more will the atmospherules of the fluid be affected, and hence the greatest action must be where the stratum of fluid is least.

Ph. 126. Although the action of the voltaic combination is greater as the connecting fluid medium is less in extent, yet the influence of even a single pair is exerted to a considerable distance: thus if a tube three feet long be filled with dilute muriatic acid, and a platina wire inserted through a cork at one end, and a zinc wire at the other, when the wires are brought into contact at the outside, gas in a short time will be evolved from the platina.

Exp. Since, when the outward contact is made, a portion of the electric fluid passes from the platina to supply that which was drawn by the oxidation from the interior of the zinc, the platina wire in the solution is rendered negative, while, from the chemical action at the zinc surface, a new portion of electric fluid is given out and again

supplied, so that this surface is continued in a positive state; the atmospherules of the particles of the liquid in the tube will be affected to a great distance, because of its continuity between the wires, especially when the liquid lies in a straight line between them: in that whole line, therefore, those atmospherules will extend from the zinc towards the platina wire, and hence the effect, although the intensity is feeble, will be propagated to a considerable distance, but less distinctly as the distance is greater.

PH. 127. If the tube just mentioned were bent like a syphon, the effect is still produced, but more slowly, and with diminished energy. Mr. *Singer* took two similar tubes of eighteen inches long, and connected them by a short piece of flexible pipe, so that he could use it as a straight tube, or like a syphon bent at any inclination: the solution and the wires being inserted as above, he found that whenever their outer ends were connected by a wire, hydrogen was evolved from the platina; but this effect took place soonest when the tube was straight.

Exp. When the tube is straight, the atmospherules of the particles of the interposed dilute acid are extended all one way, in a direct line from wire to wire, as shewn in the last: but when the tube is bent, they extend downwards in the end containing the zinc, and upward to the platina wire, the direction being changed in a curve at the bend of the tube, and this evidently will oppose some degree of obstacle to the free passage of the electric fluid; it therefore shews the reason of the fact, and tends to confirm and establish the former explanations.

PH. 128. If a zinc wire be immersed in a solution of lead, the latter metal will be revived in the form of a metallic vegetation, which increases gradually by accessions to its extremities which are remote from the zinc.

Exp. This is an instance of a single galvanic circle.

The acid of the solution unites with the zinc, and deposits on its surface a portion of lead for which it has a weaker affinity; the revived lead so adhering to the zinc forms with it and the fluid a galvanic circle, and the lead separated by the continued action is propelled as usual from the zinc and towards the revived lead, and thus continually increases it at its distant extremities.

PH. 129. Spread a few drops of solution of silver over a pane of glass, on this place two wires, the one platina the other copper, at a little distance from each other. A vegetation will be produced about the copper wire, but not about the platina.

Exp. The copper produces its effects in this case, as the zinc in the preceding phenomenon; but the platina produces no effect, because it is not acted on by the acid of the solution of silver.

PH. 130. Things being as in the last, bring the two wires into contact at one end, and then a beautiful vegetation of metallic silver will soon surround the platina wire.

Exp. By the contact of the wires a galvanic circle is completed from the copper through the solution to the platina, and from the platina immediately to the copper; hence the electric fluid flows in that course, and consequently the revived silver is propelled towards the platina, and forms the vegetation.

PH. 131. With a solution of tin, and wires of zinc and platina, similar phenomena occur; but a considerable time elapses after the contact before the vegetation appears round the platina wire.

Exp. The process is the same as before; the longer time is because of the more feeble energy.

Direction of the Electric Current.

Obs. It has been matter of inquiry, and has excited some interest, to ascertain what is the true element of the pile or galvanic arrangement: whether the two metals and moisture between them; or the two metals in contact, and the moisture in contact, with the one metal or with the other. M. *De Luc* has very ingeniously dissected the pile, so as to exhibit the effects in all the three cases, separating the several groups by means of brass tripods: he concludes that the first is the only true combination; *viz.* the two metals, and the wet cloth between them. The results of these curious experiments might have been anticipated from the contents of this section: take the substances usually employed, *viz.* zinc, copper, and dilute acid, or cloth moistened with dilute acid. Let the zinc plate be insulated, the wet cloth laid on it, and on this the copper: now we see at once, from what has been advanced, respecting both compound and simple arrangements, that as the temporary coat of oxide forms on the zinc surface, its particles, while forming, imbibe electric fluid from the zinc, rendering negative its interior, and the parts of its surface not acted on, and yielding electric fluid to the moisture by such particles of oxide as are removed from the surface, so that the action is renewed and continued; hence the moisture, and consequently the copper in contact with it, becomes positive, and the interior of the zinc, and the unaffected parts of its surface, are negative.

Here is the first action, which is transferable at pleasure under proper circumstances. If we choose to form a

single circle, we connect the copper with the unaffected parts of the zinc surface, and we at once obtain a current of electricity from the copper to the zinc. This is known to agree with fact, and constant experience. Also, this current, thus obtained, increases the effects; for by it, in the first instance, the oxide is protruded from the zinc surface, as we have before clearly shewn; hence the surface is again renewed, and tends to continue the effect: hence, also, is produced not a momentary but a continuous current, which remains as long as the action of the moisture and zinc continues, decreasing in quantity, but still long supporting the same electrical tension.

Again, if instead of forming a single combination, we wish to produce a compound one, we must not connect the copper with the zinc, as just described, but leaving these unconnected, we must form a metallic communication between the copper and the zinc plate of another similar group, that is, one consisting of zinc and copper with the moisture between them. This may be done by placing the zinc of the new group in contact with the copper of the first; which is the method in the pile, and in *Cruickshank's* trough, or by connecting them by a metallic arc, which agrees with the *couronne des tasses*, or the *Wedgewood* ware troughs: now this being done in either way, since the new group maintains the same difference, in the electric state of the copper, and the unaffected parts of the zinc, as in the first combination, and calling that difference one degree, we shall have the first liquid, the first copper, and the dry or lower parts of the new or second zinc plate, in a higher state of electric tension than the lower parts of the first zinc by one degree; but the second copper is one degree higher than the interior and lower parts of the second zinc, and consequently two degrees above that of the first. Hence, if

the last copper and first zinc of these two conjoined combinations be connected by a metallic substance, we shall have a current passing with a double intensity; thus we see how a compound combination may be extended at pleasure. If instead of insulating the first zinc, we had placed it in contact with a plate of copper, and made the last of a series of combinations to terminate with a zinc plate, we should have a small battery of the usual construction; these observations, with the 3d and 4th phenomena of this section, will, it is presumed, afford a clear knowledge of the principles of this truly surprising and interesting apparatus.

In the Manual of Electro Dynamics of *F. J. Demonferrand*, translated by Mr. *Cumming*, we have at the commencement of section 3d, the following observations: *viz.* "The direction of the current depends on the construction of the pile: if it be composed of a series of zinc and copper disks soldered together, having an acidulous solution interposed between each pair, and terminating at one end in a single copper disk, and in a single disk of zinc at the other, the direction of the current, through the conductors, is from the single copper to the single zinc, and in the pile itself proceeds from the zinc to the copper; but in the original pile of *Volta*, where each extremity is formed by a pair of disks, and where consequently all the elements are complete, the course of the current is in the opposite direction: proceeding from the zinc surface at one extremity of the pile, and passing through the attached conductors to the copper surface at the other extremity."

Doubtless by this we are not to understand, that the current passes through the series in an inverted order, for if so it would be incorrect; since the current is certainly the same way precisely in both cases, namely, from the

zinc through the liquid to the copper, then through the metallic connexion to the next zinc, whether it be in the pile or *couronne des tasses.* The single copper plate at one end, joined by a metallic conductor to the single zinc at the other end, forms itself one of the combinations of the series; and the only difference in the two cases is, that the interruption for the purpose of performing the experiment is made, when one extreme is a single zinc, and the other a single copper plate, between the zinc and copper, which should be in metallic contact to form a complete galvanic circle; and in the second case the interruption is made between two pairs of metals, which should be connected by the liquid when the circle is completed. The just idea of the apparatus in full action is, that of a complete series of any number of combinations, disposed in what we may call a circle, in regular order, so that, beginning with any one of the combinations, we proceed in the same order quite round: and an interruption may be made in any part of this circle, in order to have a place in which to interpose the bodies that we wish to make the subject of our experiments. To elucidate the preceding observations we will give some particulars of M. *De Luc's* dissection of the pile; the phenomena are taken from *Singer's* Electricity, page 441, &c. where it is stated that we may divide the pile into ternary groups, under three different aspects. 1. Zinc and silver, with wet cloth *between* them. 2. Zinc and silver, *in mutual contact* with wet cloth on the zinc. 3. Zinc and silver still in mutual contact, but with wet cloth on the side of the silver. For separating the groups M. *De Luc* employed small tripods formed of brass wire, so bent as to touch the plates between which the tripod was placed, only at the three points of support.

Ph. 132. In the first dissection an arrangement or pile

was made of seventy-six groups of zinc and silver with wetted cloth between them, each group in the pile being separated by a tripod of brass wire. Under these circumstances the same effects both chemical and electrical were obtained, as when the apparatus was put together without the brass tripods.

Exp. This follows as a necessary consequence from the last *observation*, the arrangement does not differ from the usual pile, except what may arise from the imperfect contact of the extremities of the tripods and the metallic plates, and the effects cannot differ but by the operation of that course. Neither does this differ from the *couronne des tasses*, except by the same circumstance, and the application of the moisture to one instead of to both the surfaces of the zinc plate in contact with the tripod.

Ph. 133. In the second dissection the plates were in contact, the silver lowest, and the wetted cloth on the zinc, then a tripod on the cloth, and on it the next silver plate, and so in order. With this apparatus of the seventy-six pairs the electrical effects were produced as before; but though these ceased, when the usual glass tube for decomposing water was made to connect the opposite poles, not the slightest chemical effect was observed.

Exp. The first effect between the zinc and wetted cloth is the same in this case as in the former, but the electric fluid evolved is not conveyed to the next silver plate, except only that small portion of it which is produced at the contact of the wetted cloth and the feet of the tripod, and even that quantity not with perfect freedom, because of the incomplete contact of the wire and silver plate, Now this happens because the intensity of the electricity is so low that the wetted cloth serves as an insulator at the parts without the metallic contact, and this insulation is the more complete, both because of the raised electrical

state at the feet of the tripod, and because of the imperfect contact with the silver. From this it follows that the electric effects will be the same as before, because these do not at all depend on the extent of surface, but on the number of combinations, on this account the small surface of the points of the three wires of the tripods will affect the electrometer as much as if the whole surface of the plates had acted by being placed on the cloth. But the chemical effects will, in the decomposition of water, be inappreciable because of the exceedingly minute portion of electric fluid transmitted.

Obs. It is inferred from this, that the condition for the production of chemical and electrical effects is different, the latter requiring the arrangement of silver and zinc in mutual contact, the successive pairs being separated by a moist conductor, which may be in actual contact with the zinc only: the former requiring the association of silver and zinc, with wetted cloth *between them.* But the preceding explanations shew that no difference in the essential condition has place, except as usual in respect of quantity, which indeed operates in the present instance against the evolution of electricity from the plates; for as in several places we have shewn that oxidation, and protrusion of the oxide formed is much increased by the electric current, and consequently the evolution of the electric fluid is also much increased. The explanation given of this phenomenon will also shew the reason of the advantage obtained by Dr. *Wollaston's* contrivance of extending the copper to both surfaces of the zinc plate; nothing is gained by it in intensity, but much in quantity.

Ph. 134. In the third dissection the plates were still in mutual contact, but the zinc was lowest, and the wetted cloth on the silver; on that was placed a tripod, and on this again another zinc plate, and so on in the regular

order. In this case neither chemical nor electrical effects were produced.

Exp. The first effects between the silver and the wetted cloth are very small, because of the less action between the menstruum and silver, than when in contact with the zinc, and this very small effect is counteracted by the tendency of the electric fluid of the silver towards the zinc with which it is in contact, (*ph.* 1), hence there is in this case no electrical current whatever, and no chemical or electrical effects can consequently be produced.

Ph. 135. When several batteries are united, if there be an imperfect connection in any of the series, a great diminution of power is the consequence.

Exp. This must occur because the imperfect conductor, forming the connection, can transmit only a small part of the quantity of electric fluid produced, and this happens because of the low electric intensity in all cases.

Ph. 136. If one plate be corroded or covered with more oxide than the rest, and the coat is too thick for the greatest effects, there is a general loss of the entire action.

Exp. A thick coat of oxide, which is a bad conductor, must evidently have a similar effect to the imperfect connection in the last phenomenon, because it is itself in reality a very imperfect conductor, and indeed when very thick it is a non-conductor to electricity of low intensity.

Obs. The tendency of the action is to equalize the coat of oxide on all the plates, and by the changing of this transitory surface, the effect is continued.

Ph. 137. If copper be substituted for zinc, or zinc for copper, in a single series the result is similar.

Exp. For in this case an obstacle to the uniform passage of the electric fluid is presented, and thus, as before, a deficiency in the effect is the consequence.

Ph. 138. " A platina wire introduced in the place of an

arc of silver and zinc, in a series of thirty, diminished its power of producing gas so much, that it was only equal to that of four."

Exp. The platina wire is not acted on by the solution, hence the different electrical states of its two ends is not affected, as far as that action is concerned, (*ph.* 119, 120, and 121,) hence the connection is imperfect, and as before impairs the action.

Obs. This and the three last phenomena are taken from Sir *H. Davy's* Chem. Elem. p. 158.

The electric Column.

M. *De Luc* in consequence of his experiments was led to construct a pile without the intervention of a liquid, and thus he obtained an instrument producing electrical effects as usual, but not the chemical effects of decomposition; this he named "the Electric Column." Mr. *Singer* has made experiments with columns of this kind on an extensive scale. He recommends the following construction. Silver leaf is laid on paper, so as to form silvered paper, from this, and also from writing paper, and from very thin sheets of zinc, circular plates about $\frac{5}{8}$ of an inch in diameter are cut out by means of a hollow punch. These are arranged in the order of zinc, paper, silvered paper with the silvered side upwards, zinc upon this, and so on in the same order; the series being continued till 1500 or more groups are connected. They are placed either in a glass tube or between three glass rods covered with sealing wax, and fixed on a foot of wood.

PH. 139. An extensive series such as that above described is found to affect the pith ball electrometer considerably. When the column is insulated, the balls of an electrometer attached to each end diverge, the one by positive, and the other by negative electricity, but one attached to the middle, is not affected. The proper arrangement is, first silvered paper with the silvered side uppermost, on this zinc, thin paper; and then silvered paper, &c.

Exp. The first plate of zinc will receive a portion of electric fluid from the silver with which it is in contact, so that the zinc will be positive and the silver negative, (*ph.* 1). Now the paper next on the zinc although not a conductor of electricity of low intensity, will, from its proximity to the zinc, and more because of its fibrous and porous nature, slowly receive the same electrical state as that of the zinc on which it rests, and hence the second disc of silver will be brought into the same state as the antecedent zinc plate, and the interposed paper will maintain this difference, because it has in general no tendency to return, and the paper is sufficiently a non-conductor under very small variations. Things being in this state, a second zinc plate is laid on the second disc of silver, and being in contact, it abstracts from it as before a portion of its electric fluid, (*ph.* 1), this takes off from the interposed paper, and consequently from the lower zinc, its previous state of equilibrium, and consequently the resistance which prevented it from attracting more electric fluid from the silver with which it is contact; hence the first zinc therefore now takes more electric fluid from the first silver, and in sufficient time communicates it to the silver and zinc above it, so that, when the equilibrium is attained, there will be the same difference as before in the electric state of the first silver and zinc, and hence each

will be diminished by one degree of difference, as before, in the electric state of silver and zinc, and hence each will be diminished by one degree of difference; and the newly applied zinc will become one degree higher in its electric state, than that of the preceding one before this was added: thus while there was only one group the silver was one degree negative and the zinc one degree positive, and hence the second group renders the first silver two degrees negative, first zinc and second silver neutral, and the second zinc positive two degrees. Similar effects must of course be propagated throughout the series between every pair, a regular increase being made for every new group that is put to augment the series, time being allowed for the equilibrium to be acquired. The paper and silver disc of every group will be in the same electrical state, as the zinc on which it rests, and two degrees lower than the zinc which is on it in contact with the silver.

Hence the state of the apparatus in respect to the electricity of the plates may be represented as in the following table, beginning with one group and increasing by one in each horizontal line; the first vertical column shews the number of groups in the series.

No. of Groups.	1. Silver.	1. Zinc and 2. Silver.	2. Zinc and 3. Silver.	3. Zinc and 4. Silver.	4. Zinc and 5. Silver.	5. Zinc and 6. Silver.	&c.
							&c.
1	— 1	+ 1					
2	— 2	0	+ 2				&c.
3	— 3	— 1	+ 1	+ 3			
4	— 4	— 2	0	+ 2	+ 4		
5	— 5	— 3	— 1	+ 1	+ 3	+ 5	
&c.	&c.						

The single line (—) before the figures denotes that the plate is negative, the character (+), denotes the positive

state, and the figure, before which the line is placed, shews the number of degrees by which it is below the natural state; the figure to which the cross is prefixed shews the degrees above the natural state, the natural state is itself designated by 0, or zero. It is evident that each degree must denote a very minute difference of the electrical state, such as is not easily appreciable by the most delicate instruments, and it is only from the great extent of the series, that they become very distinct and easily discernible.

Ph. 140. If one end of the insulated column be connected with the ground, the electrometer attached to that extremity will close, the central one will open with the same electricity, and the divergency of that at the opposite end will be considerably increased; but some minutes will be required to produce the effect to its highest limit.

Exp. Because of the connection with the ground the state of the first paper and silver disc soon become neutral, and the zinc in contact with it will maintain a state two degrees higher, as shewn in the last phenomenon; this will be propagated through the paper to the next silver, and the second zinc will be raised two degrees above it or four above the first silver, and in like manner the effects will pervade the whole series; but some considerable time will be required for this purpose, because the paper is a very imperfect conductor; were it not for its fibres in contact with the zinc, probably it would not act at all.

Ph. 141. If the two extremities of the column be connected by a good conductor, for a considerable time, the instrument, for hours after the connecting medium is removed, will scarcely affect an electrometer, and it is some days before it acquires its full power.

Exp. It is evident that in consequence of the communication between the extremities, they will soon be

reduced to nearly the same electrical state, because the motion of the electricity is impeded by the paper, and the quantity developed is very small, and hence the whole apparatus will soon be nearly in a natural state, the connection continuing; and when afterwards this is removed, for the same reason, *viz.* the feeble conducting power of the paper, it will be a long time before the power of the column is again fully established, usually some days.

PH. 142. If an extensive column be well insulated, and a bended wire connected with the top, and supporting a metallic ball, be brought near the other pole, furnished with a similar ball, then a small brass ball being freely suspended between them, will oscillate continually for years. If, instead of the balls at the poles of the column, two bells be suspended, a perpetual chime will be produced. The apparatus may consist of two series of about eight hundred, or a thousand groups, each one of which has its positive pole at the top, and the other at the bottom, and these being well connected at the top, form one complete series with their opposite poles near each other, which may be furnished with bells, and a small ball suspended between them; the whole may be covered by glass. This arrangement was contrived by Mr. *Singer*. On taking an apparatus of this kind to pieces, which had been constructed thirty months, no signs of oxidation by the plates were observed.

Exp. The two poles being in opposite electrical states, the pendulous ball is alternately attracted and repelled by each (*ph.* 84, and 85, *sect.* vii); hence the motion is produced, and because the parts of the apparatus are dry and well insulated, no oxidation takes place, and the action of the plate continues by the aid of the oxygen, and other air which simply adheres to the plates, (see *ph.* 1, and 139); and thus the chimes, or the motion of the pendulum will

be perpetuated in a well constructed series, at least for several years.

PH. 143. The oscillations of the pendulum, as described above, are much more rapid at some times than at others, and on some occasions they are very irregular.

Exp. The variations of the weather, and different states of the atmosphere, both in respect to density and moisture, as well as to temperature, are quite sufficient to account for these irregularities in the action of the column, since every group in the series will be affected by these circumstances.

PH. 144. Although the motions of the pendulum are variable, yet they are continual, unless the two ends have been connected by a good conductor for some time; in that case it loses its power, which is recovered again in a few days, if well insulated, and the connexion removed.

Exp. This is explained as *ph.* 141, which see.

PH. 145. Mr. *Singer's* series of twenty thousand groups charged an electric jar, containing fifty square inches of coated surface, by remaining ten minutes in contact with the column, and the discharge was sufficient to perforate thick drawing paper.

Exp. The jar is charged in the same manner as when one of its sides is connected with the positive, and the other with the negative conductor of an electrical machine, the only difference is in the degree to which it is charged, owing to the different intensities of the instruments. The common voltaic battery will charge the jar in a very small time, but the column takes a longer time, because of the slow progress of the electricity through the apparatus.

PH. 146. Notwithstanding the electrical effects of the column, it does not produce the chemical effects of decomposition, which are readily effected by the voltaic pile.

Exp. In order to produce the chemical effects, a dense though small current is requisite; but in the column, although the electrical intensity is considerable, yet at once it is nearly equalized, when the poles are connected by a conductor, and then the electro-motion is very slow, as appears from the phenomena already explained respecting this instrument, and because the quantity is exceedingly small, as well as the motion very slow, no chemical decomposition can be effected by this apparatus, as above constructed.

SECTION IX.

MAGNETISM.

THERE is a certain ferruginous mineral denominated the Magnet, it was formerly considered as a species of stone called the loadstone; this mineral possesses several very remarkable properties; for instance, it exhibits a peculiar apparent attraction and repulsion; it assumes a particular direction in respect of the meridian, when it is freely suspended, this is called its declination; it also takes a particular direction in respect of the horizon, called its dip or inclination; it is subject to great variations in all these respects; its direction is affected and changed by the action of a continuous electric current on it, or by other continuous currents of ethereal matter; it can communicate its properties to iron and steel, also to nickel and cobalt; its properties may also by other means be produced in the last mentioned bodies. The property first

noticed above, was the only one known to the ancients, as far as we can learn from their works. The earliest account we have of the discovery of its directive property is in 1260, by *Mark Polo*, a Venetian. *Seb. Cabot* discovered its declination in 1500; and the variation of the declination was first detected in 1625, by Mr. *Gellibrand.* In 1576 Mr. *R. Norman* discovered the dip, or inclination. The action of a continuous ethereal current on the magnet was first clearly ascertained by Professor *Oersted*, of *Copenhagen*, in 1819, and from this has resulted a much clearer knowledge of its properties and actions. The science which investigates and explains these various properties is denominated Magnetism, of which Electro-Magnetism is a particular branch. Magnetism will be the subject of this section; and because the magnetic powers are constantly influenced by the electrical state of the air, and by the Aurora Borealis, we shall commence the section by presenting several phenomena in atmospherical electricity.

Atmospheric Electricity.

Ph. 1. The rapid evaporation of water generally leaves the vessel in which it was evaporated negative, and the body on which the vapour condenses becomes positive.

Exp. Water, during its conversion into vapour, absorbs large quantities of ethereal matter, from those contiguous bodies which yield it most readily; hence it will absorb electric fluid from the vessel which contains it, and will thus leave the vessel negative; when it is again converted into water, it gives out the electric fluid which it had

received, and hence renders the body on which it condenses positive.

Ph. 2. The electrical appearances of the atmosphere are displayed most of all at or near the periods of the greatest heats.

Exp. During the increase of the temperature evaporation is going on briskly, and therefore electric fluid is rapidly absorbed, (*ph.* 1), and when condensation again takes place, a new and opposite electrical change occurs; hence, when great heat prevails, electrical effects may be expected.

Ph. 3. The electrical phenomena of the atmosphere, within and near the tropics, are very frequently exhibited on a grand scale.

Exp. In these regions great quantities of the electric fluid must be continually raised by the expansion of the air, and by evaporation; hence, frequent and often grand electrical effects will necessarily be produced in those regions.

Ph. 4. Within the tropics the appearance of the electric fluid called sheet lightning is often seen playing in the upper regions of the air during the evenings.

Exp. This is the natural consequence of the great quantities of electric fluid raised there, together with the heat and rarity of the air in those upper parts of the atmosphere.

Ph. 5. Changes of the wind, and opposing currents of the wind, produce electrical changes.

Exp. This must necessarily arise partly from the friction of the different currents, partly from the change produced on such occasions in the temperature and density of the air, and partly from the difference in the state of the air coming from the opposite regions.

Ph. 6. Great and rapid changes in the degrees of heat

and cold are attended by frequent and corresponding electrical changes.

Exp. Since effects are in a regular manner dependent on their causes, we can be at no loss to see the reason of these appearances, especially if we consider the 1st and 2d phenomena.

Ph. 7. The electrical effects of the atmosphere are most apparent at the greatest altitudes.

Exp. From the great rarity of the air in the higher parts of the atmosphere, a proportionately greater quantity of the electric fluid will be present, and its passage will therefore be more free (*ph.* 13, *sect.* vii) when slight changes occur in the air; hence the electrical state will be more sensible in the higher regions.

Ph. 8. Fogs, rain, snow, hail, and sleet, usually render the air negative at first, and then positive, making it change its state every three or four minutes.

Exp. Since the evaporation and condensation of moisture produce electrical phenomena, and since also the motions of bodies amongst each other excite similar effects, it follows that fogs, rain, &c. must alter the usual electrical state of the air, and since this, as will be shewn, (*ph.* 10), has a continual tendency to become positive, these frequent and rapid changes occur under the above-mentioned circumstances.

Ph. 9. Explosions of the electric spark are sometimes observed between neighbouring clouds, or between the earth and a cloud, exhibiting the phenomena of lightning and thunder.

Exp. When, by the rapid condensation of vapour, or by the friction between the air and vapours, or between different currents of air which frequently exist, especially during thunder-storms, clouds are rendered electrical, and charged as the prime conductor of an electrical machine,

or as the Leyden phial; the explosion will take place, producing a powerful spark, whenever a neutral cloud, or one in an opposite electrical state, is near enough to cause the discharge, or when the charged cloud is so near the earth as the striking distance requires. The astonishing effects of these magnificent, and sometimes tremendous phenomena, are such as we should be led to expect, when we have become familiar with those, which may be produced by a powerful electrical machine.

Ph. 10. In the usual state of the atmosphere its electricity is invariably positive.—*Singer.* This relates particularly to the atmosphere in high northern latitudes, and is an important fact, which agrees with the observations of electricians in general, and is confirmed by the experiments of *Gay Lussac* and *Biot*, made in a balloon at the height of 4000 metres above the earth's surface, a wire, being let downward and insulated, was found to be negative at the top. We are authorised to conclude, that the same phenomena occur in southern latitudes.

Exp. In order to understand the reason of this, and to unfold its causes, conceive, for a moment, that the several parts of the earth and its atmosphere are at their mean temperatures, and that the whole is in its natural state of equilibrium. Then it is manifest, that the distribution of the electric fluid, in the atmosphere, will depend chiefly on the temperature, and the density of its different parts; and that in the torrid zone, a given volume of air at a given altitude, will contain more electric fluid than an equal volume at the same altitude in higher latitudes, both on account of its greater temperature, and its greater tenuity; for, in order to support the equilibrium, the several atoms of air must require a much greater quantity of ethereal matter, such as the electric fluid, caloric, and light, to complete their atmospherules: much more then

will a zone of a given breadth, in the tropical regions, contain a greater quantity of electric fluid than such a zone in higher latitudes, the zone being terminated by parallels to the equator; for the zone near the equator is evidently much greater in circumference, and its elevation above the earth's surface is also greater; hence it will contain abundantly more electric fluid. Again the distribution of the electric fluid in the earth itself will be according to the form and nature of the parts of its surface, and the resistance to its passage into the atmosphere, and hence in the equatorial regions, the electric fluid will be more dense, and in greater quantity, than in high latitudes, since this is necessary for the support of a greater quantity, which the atmosphere contains in those parts, and to prevent the more facile return of the electric fluid to the earth in consequence of the better conducting state of the air in the warmer climate, on account of its rarity, and increased temperature.

Having once conceived this state of things, next consider the changes which will occur, and first advert to the sun's diurnal progress, elevating the temperature on the meridians successively from east to west, but particularly and most of all in the latitudes answering to his declination, and in the contiguous latitudes. The air thus rarefied in the equatorial regions, will absorb electric fluid and other ethereal matter, also the cold air rushing in to supply that which is elevated by the heat and consequent rarefication, and producing the trade winds, will in its turn be rarefied and absorb additional ethereal matter, which is supplied by the earth at those places: now it is evident that the elevated air loaded with ethereal matter will flow at the top of the atmosphere towards the north and south poles, while it pursues the diurnal course of the sun, this twofold motion will produce a spiral current of rarefied air, and

the electric fluid in the upper regions will gradually diffuse itself, and sometimes, from various causes, copiously mix with the other parts of the atmosphere; now this air being condensed towards, and in the polar regions, will discharge its electricity to the earth as it advances northward, and much more so because large portions of the electric fluid of the earth, in these high latitudes, are continually conveyed towards the equator, to supply the waste there, and to maintain the equilibrium; for it is evident that the fluid elevated in the torrid zone cannot return the same way, because additional quantities are continually raised; it must therefore be conveyed in the rarefied air at great altitudes northward and southward. From this it clearly follows, that the atmosphere in high latitudes becomes charged from the elevated regions, and is in a state fit to communicate electricity to the earth, and is therefore usually in a positive state, the deviations from this state, which sometimes happen, arise from partial and adventitious causes. It is likewise evident that a current of ethereal matter is produced round the earth in the same spiral form.

PH. 11. The usual positive electricity is weakest during the night, it increases at sun rise, decreases towards the middle of the day, and increases as the sun declines, it then diminishes and remains weak during the night.—*Singer* on Elect. p. 275.

Exp. During the night the air is colder and more dense than by day, and hence it does not so freely transmit the electric fluid from the upper regions, and therefore is less sensibly positive, at all altitudes at which we can make experiments: at sun rise the first impression of his rays is to warm and rarefy the air at the earth's surface, this air therefore is put into a state, in which it tends to receive

the electric fluid, but this it cannot obtain from the earth, which is already in defect, from the discharge towards the equator, and the small supply which is contributed during the night; but the upper regions of the air, which are less affected by the sun's rays, and have accumulated electricity during the night, are in a state suitable to afford the supply readily, and to convey the usual quantity to the earth; hence, the positive electrical state increases for a short time. Again, when the whole body of air begins to be warmed, and rarefied, it absorbs more electric fluid in the parts moderately elevated, and transmits less, so that about the middle of the day the positive state decreases; but, as the sun declines, the rarefied air condenses, and hence gives out electric fluid, which cannot be communicated to the air above, that being already surcharged, it therefore transmits it to the earth, and hence the positive signs increase at the decline of the sun: lastly, when the air has become sufficiently cooled, and dense, the electricity is less freely transmitted, and the weak positive state continues during the night.

Obs. It is manifest that these regular phenomena will be greatly modified, and diversified by the circumstances noticed above, and by various others which frequently occur.

Appearances of the Aurora Borealis.

The Aurora Borealis is a beautiful meteor, seen chiefly in the nothern regions, particularly in the spring and

autumn. Meteors of this kind present various appearances, connected with electricity and magnetism; the principal of these we may now proceed to explain.

Ph. 12. Sometimes the Aurora is very mild, resembling whitish clouds illuminated by the sun or moon, so that they may be taken for such clouds by persons unaccustomed to observe this meteor. They appear in the northern sky, and often yield much more light than the stars, the nights on these occasions being more light than usual in the absence of the moon.

Exp. The progress of the electric fluid in the upper parts of the air, towards the poles, as described in *ph.* 10 and 11, is continually more and more interrupted by the increasing density, coldness and dryness of the air, as we recede from the equator; the spirally revolving current of electric fluid will therefore more and more tend towards the earth, and especially, the upper regions will be more fully saturated with that fluid; hence when, from warm winds or other atmospheric changes, thin moist clouds become diffused towards the frigid zones, they will become conducting vehicles, for conveying large quantities of the electric fluid to the ground. Now from the well known properties of the electric fluid flowing from one body to another, it follows that the thin moist clouds, thus conveying it will be rendered lucid at their extremities, and in those parts where any interruptions of contiguity are found; and this is doubtless the most common, but the least noticed kind of Aurora Borealis.

The following phenomena contain a description of the most conspicuous and complete Auroras.

Ph. 13. (1) Generally the first appearance of the Aurora Borealis is that of a sort of thin cloud in the north, like a dark, grey, or whitish mist, forming an arch whose extremities are connected by the horizon as a chord, its

summit rises a few degrees above the horizon, seldom less than 6°, but sometimes its vertex is elevated 50° or even 60°. This may be called its dark segment. On the upper border of the dark segment is a very lucid arch from one to five or six degrees broad, often rising a little higher in some parts than in others.

Exp. When from different circumstances an unusual dryness and coldness in the frigid zone, freezing the vapours, and condensing the air, happens to take place, the progress of the electric fluid as noticed in *ph.* 10, 11, and 12, will be considerably retarded, because of the greater non-conducting property of air thus affected. Now things being in this state, if there should be a sudden change of temperature, such as is known frequently to occur on various occasions, it will produce a dampness in the air, and the accumulated electric fluid will descend from the higher regions copiously on it, causing the luminous border, and the light of this border will give to the thin moist vapour, the appearance of the dark segment. This segment will therefore be seen in the north, and will be less or more elevated according to the situation of the thin warm and moist vapour. Also the lucid border, will be of less or greater breadth according to the degree and state of the vapour, and the quantity of electric fluid discharged. Again from all this we should expect to find the arch irregular in breadth, rising to different heights in different places.

Ph. 14. (2) Sometimes a lucid limb has been observed on the lower side of the dark segment.

Exp. This appearance will be seen when the warm vapour does not extend very far down towards the earth, for in that case, the electric fluid leaving it abruptly will manifest the fringe of light.

Ph. 15. (3) The bright stars may frequently be seen

both through the dark segment and the lucid border, and sometimes, although seldom, small stars may be seen through them, especially through the luminous part.

Exp. We have supposed that the moist and warm vapour is very thin, and indeed, since most probably it is brought from the tropical regions in the higher parts of the atmosphere, it will necessarily be very thin and diffused, and hence the bright stars will sometimes be conspicuous even through this dark segment, and the electric fluid entering copiously will not diminish, perhaps sometimes will greatly increase, the transparency of that part of the air.

Ph. 16. (4) The dark segment with its lucid border is extended sometimes farther towards the west than the east; sometimes farther towards the east than the west, and usually takes up a quarter of the horizon, more or less. Sometimes however it occupies only five, or six, and sometimes a hundred degrees.

Exp. The situation and extent of the arch will depend considerably on those of the thin vapour above noticed, which may be greatly diversified.

Ph. 17. (5) Pillars, or beams of light, appear to dart upwards from the dark segment, and luminous arch; these are white, yellowish, or green at their bases, but become orange and red as they rise towards the zenith, or some point near it, to which they continually tend.

Exp. The electric fluid descending abundantly towards the dark segment, as above described, from all sides, will find a more facile passage in some portions of the air, than in others, as will be readily admitted by any person conversant in electrical experiments, especially such as relate to atmospherical electricity, hence the luminous beams will seem to rise upwards from the dark segment, though in reality the electric fluid flows downwards to-

wards it; but the light of these beams must first appear at the place of ingress, and the light will of course appear to extend upwards.

Ph. 18. (6) These pillars or beams of light appear to be arcs of great circles, verging towards that point in the heavens to which the dipping needle is directed, when properly suspended, they seem to get smaller as they rise, so as to take a conical figure, whose vertex is the place towards which they are directed; and also the dark segment with its lucid border extends towards the magnetic east and west.

Exp. The gyrating ethereal matter, especially the electric fluid, finding a resistance to its motion towards the pole (*ph.* 13), from the greater non-conducting power of the air, on account of its greater density and coldness, and the frozen or crystallized state of the aqueous vapour in these cold climates, will find its way most copiously towards the earth at some distance from the pole, this being favoured by the motion of the electric fluid in the earth towards the equator, (*ph.* 10 and 11); hence there will be a zone or space of the earth's surface at some distance from the pole, most probably within the polar circle, at which zone the electric fluid will enter the earth more than at any other part. This zone will be irregular on account of the different conducting power of the several parts of the earth's surface. Now this irregular space or belt being of unequal conducting power will admit a more free entrance for the electric fluid at some parts than at others, (or if not of unequal conducting power from the various states of the air, a tendency of it to enter at one part more than another will happen); and the fluid, copiously entering at one of these places, will produce a diversion of the electric current towards it from the surrounding parts, for the discharge there renders the air

more fit to receive and convey a continued stream; hence this place will become a kind of pole, occupying a space probably of several miles in extent, which, as we shall see in explaining the phenomena of magnetism, gives a certain direction to the dipping needle. Now since the electric fluid is most copiously discharged at this place, a comparatively small portion will be discharged in the neighbouring parts of the irregular zone, and we may expect that a similar place of entrance for the electric fluid will be found at some other part of the zone nearly opposite; also in consequence of these poles the entrance of the electric fluid into the earth will be increased in certain lines directed through this pole and the places of the adjacent hemisphere; these lines will be affected in their direction and course by the nature of the earth's surface between the place and the pole, and this is found to determine the magnetic meridian of the place through which it passes; a great circle at right angles to this magnetic meridian, cuts the horizon in the magnetic east and west. All this being considered, it will be manifest that the electric fluid descending on the dark segment, and forming the luminous arch, will tend to shew itself equally on each side of the magnetic meridian, and hence the dark segment will be directed towards the magnetic east and west. The same will shew that these beams might really be cylindrical, or even broader in the more elevated parts, yet they will generally be seen to converge to the point of apparent concourse.

Ph. 19. (7) The dark segment is frequently bisected by the magnetic meridian; but sometimes it deviates more to the east or to the west: also, the luminous pillars or beams are not always directed to the same point of the magnetic meridian.

Exp. The tendency of the electric movements will be

to exhibit the light in these positions; but evidently considerable variations will arise from the situation of the warm moist vapours, and other circumstances, whether of a general or local nature.

PH. 20. (8) Flashes of light succeed the beams, darting upward in the same direction with them, they are momentary, and rapidly succeed each other. They are broad and diffuse, and consist of weaker light than the beams. They appear and disappear so quickly as to produce the impression of a tremulous motion.

Exp. All this is exactly answerable to what we should expect from the motions of the electric fluid in the upper and rare parts of the atmosphere in the directions as above explained.

PH. 21. (9) The flashes often dart quite up to the zenith, and sometimes beyond it; they then generally form near the zenith a sort of canopy of encircling light, called the corona: at this period the Aurora displays its greatest splendour.

Exp. These remarkable effects are nothing more than what has been already explained, except in degree, such appearances may be expected when an unusual quantity of electricity has been accumulated in the elevated parts of the atmosphere, through a long continuance of serene cold and dry weather.

PH. 22. (10) Frequently arches in the form of a rainbow, sometimes one, at other times two or more, are seen, which when complete go quite across the heavens, at right angles to the magnetic meridian, meeting the magnetic east and west, when these appear they are generally first seen.

Exp. These rainbow-like arches are of the same nature, and arise from the same cause as the lucid arch on the dark segment, (*ph.* 13 and 14); they will therefore be

understood from those, and that they cross the magnetic meridian at right angles, or nearly so, will follow from *ph.* 18 and 19; this position depending on the place where the electric fluid enters the earth in the greatest quantity, in order to be conveyed towards the equator.

PH. 23. The ten phenomena just described are those which the Aurora most generally exhibits; but sometimes there are others, and frequently some of these are wanting.

Exp. The cause of these appearances which are assigned in the above explanations, will fully unfold the reason of this, the state of the air, the position and extent of the warm watery vapour, &c. will cause great variations to occur, and all the above described phenomena will seldom be seen at once.

PH. 24. Auroræ Australes, or Southern lights, are seen towards the south pole; some of them are very brilliant, as observed by *Cook, Foster, Bailey,* and *Wales,* from the year 1772 to 1775.

Exp. All that has been said in the last thirteen phenomena respecting the Aurora Borealis, will apply to that which appears in the south, excepting so far as it is modified by the difference in the earth's surface.

PH. 25. "The inhabitants of the Northern countries observe the Aurora to be remarkably strong, when a sudden thaw happens after severe cold weather."—Dr. *Priestley's* History of Elect. vol. i. p. 437.

Exp. During the cold weather, the electric fluid accumulates in the upper parts of the atmosphere, because the frost renders the lower parts of the air a worseconductor, by increasing its density, but much more by congealing its vapour; but when the sudden thaw takes place, the thin watery vapours will be diffused in the higher parts of the air, and hence the Aurora will occur. This agrees

with *ph.* 13, and greatly corroborates and confirms the explanations we have given of this meteor.

Ph. 26. Auroræ Boreales are seen very frequently in the northern regions; they are of more rare occurrence as we advance towards the equator, so that in latitudes lower than 35° or 40° they are scarcely ever, if at all observed.

Exp. As we advance towards the north, the spiral currents of electric fluid moving north-west, (*ph.* 10 and 11), are more and more arrested, as above explained, and much contracted by their shorter revolution near the pole, and hence the Aurora will be more frequently seen the nearer we come towards the northern magnetic pole. But the causes we have assigned, and which as we have shewn evidently exist, indicate that they ought not to be seen in the parts of the earth near the torrid zone.

Ph. 27. These meteors have been observed at all seasons of the year, but are most common at the spring and autumn, and even during winter, when the weather is serene and clear.

Exp. The changes in the weather are most frequent at the spring and autumn, and often after serene weather in winter a period of warm days ensues; but there is a more uniform warmth and moisture in summer: hence (*ph.* 13 and 25) these meteors should be seen as above stated.

Ph. 28. In some years they are more frequent than in others.

Exp. The weather in some years is found to be far more uniform than in others, and consequently less favourable for producing these phenomena.

Ph. 29. As the motions of the Aurora cease, the light approaches more and more towards the horizon, contracting from the east and west, and terminating near

the north; the dark segment, becoming luminous, disappears with greater or less rapidity.

Exp. This close of a brilliant meteor, depending, as above explained, on the electric fluid, and taking the positions specified, is such precisely as the circumstances would lead us to anticipate.

PH. 30. On Sept. 29, 1828, a fine rainbow-like arch was observed in *England:* at *Bristol* it was seen to rise a little before eight o'clock in the evening from an apparent cloud, or thin vapour, nearly at the WSW point of the horizon, it passed a few degrees to the north of Altair, in the Eagle, and nearly at right angles to the line produced which joins β and γ in that constellation, it proceeded along by Sagitta towards the ENE point of the horizon, passing a little to the south of the Pleiades in the east. It was of a yellowish pale white colour; it was seen in its greatest splendour at about a quarter past eight, and gradually faded, so that about nine it was scarcely discernible. It shifted its position a little; its breadth towards the west was about six degrees, but towards the east it was about three or four degrees broad. Nothing more of the Aurora was observed at the time, except a faint light, and a few feeble flashes of light which appeared towards the north, after the arch became invisible.

Exp. This is only a particular case of these meteors, and agrees with *ph.* 22, where it is shewn, that when such arches exist, they are first seen; sometimes there are two or three of them seen at once, and they are frequently unaccompanied by most of the other parts of the Aurora.

Mr. *Dobbs* mentions several similar arches seen in *Ireland*, Sept. 24, 25, 26, 1725. Phil. Trans. No. 395, p. 128.

Mr. *Howard*, in his important work on the *Climate of*

London, records the following account of a similar Aurora. *Edinburgh*, March 6. "A little past eight o'clock, p. m. a beautiful Aurora Borealis, nearly resembling that which appeared in September last, was distinctly visible here for a considerable time. A similar beautiful arch of bright light stretched across the heavens. It sprung from a point nearly ENE, and passing the zenith, terminated in the opposite point of the horizon. Its eastern limb was the brightest and best defined. The horizon in almost every point was obscured by dark broken clouds, which rendered both its beginning and termination less distinct than the last."

The three following phenomena are taken from Professor *Hansteen's* paper, Phil. Mag. Nov. 1827, p. 336.

PH. 31. The columns of light shooting up from the northern horizon towards the zenith are unconnected, short parallel rays, or cylinders of light, whose direction nearly coincides with that of the dipping needle. When these columns pass the zenith, they seem broken off, and form the crown.

Let N C S, *fig*. 73, be a part of the magnetic meridian, F *f*, E *e*, and D *d*, parallel rays forming the Aurora. If the observer at C turn his eyes in the direction of CF, CE, CD, a part of each column is covered by that in front, and the whole mass of light from F to Z, and Z to D, seems connected. But in the direction CZ one only sees the transversal section of the column, and hence the blue sky appears. The light also seems connected, if we look towards the east or west; hence the whole seems to rise to the magnetic zenith.

Exp. What is here stated and illustrated, agrees with the explanations we have advanced in the preceding phenomena, and requires no other principles or explanation.

PH. 32. In the magnetic meridian these rays seem per-

pendicular to the horizon, but towards the east or west they have an inclination towards the south, as represented in *fig.* 74; thus every observer will see the crown in *his* magnetic zenith, and therefore each sees a different crown; hence the altitude cannot be found by observations at different places.

Exp. The facts here noticed are fully explained in *ph.* 18, and agree with all that has been said on this subject.

Ph. 33. The rays are frequently seen to form into a regular ring, DE, *fig.* 75, darting from a small zone of the earth's surface, the center of which is somewhere north of *Hudson's Bay*. If BC be the horizon at C, the angle FCB is the elevation of the lowest arch, and ECB of the highest.

Exp. Since the electric fluid, as shewn *ph.* 18, will find its way to the earth most copiously in an irregular zone, and particularly at some certain places in that zone, it will follow that in some cases of the Aurora, the appearances above mentioned will occur; and the space occupied by the ring is evidently the place in the irregular zone, (*ph.* 18), where the ethereal matter is discharged from the atmosphere in the greatest abundance.

The four following phenomena are taken from Mr. *Richardson's* paper in the Edin. Phil. Jour. for July—Sept. 1828; the observations were made in the land expedition in 1825, 6, and 7.

Ph. 34. The Aurora Borealis is generally most active when it seems to have emerged from a cloud near the earth.

Exp. The nearer the thin watery vapour (*ph.* 18) is to the earth, the more rapidly it will convey the electric fluid, and the more brilliant will be the coruscations of the Aurora, which agree with the facts here stated.

Ph. 35. When the Aurora is very active, a haziness is perceived about the coruscations, though the sky in other parts is very clear.

Exp. The vivid light of the Aurora will render the slender mist, by which it is conveyed, sufficiently opaque to exhibit the apparent haziness.

Ph. 36. A low temperature seems favourable for the production of brilliant and active coruscations.

Exp. What has been advanced on *ph.* 25, will shew the reason of this fact.

Ph. 37. The gold leaf electrometer was not affected by the appearance of the Aurora.

Exp. It is not to be expected that it should affect this instrument; for the Aurora takes place in the elevated regions of the air, and the air at those places of observation is not irregularly, or suddenly, or in any very great degree affected by its action.

Obs. Mr. *Richardson* observed that brilliant and active coruscations of the Aurora Borealis cause a deflection of the magnetic needle, and that almost invariably, if they appear through a hazy atmosphere, and exhibit the prismatic colours. This will be understood from the magnetic phenomena which follow. The altitude of these meteors is considerable, but by no means so great as many have imagined, as appears from the observations of Mr. *Richardson*, and others. There are many sources of fallacy in observations on these lights.

Ph. 38. The corona is not always formed exactly in the point of the heavens towards which the dipping needle is directed, nor is it always stationary during the short time of its appearance, but approaches towards the point just now specified: thus, that which was noticed by Dr. *Halley*, Phil. Trans. No. 347, p. 406, first appeared a

little to the northward of the zenith, but gradually declined towards the south.

Exp. The direction of the beams, pyramids, and flashes of electric light will be greatly affected by the state of the air, and the position of its vapours; but the tendency, as before shewn, will be such as to influence the streams so as to direct them towards the point we have mentioned.

PH. 39. Some of the beams of light frequently have a lateral motion, verging either towards the east or west, still retaining their position nearly at right angles to the horizon.

Exp. Such motions will ensue from a like motion of the thin vapour, where the discharge takes place, or from a variation in its conducting power when it is extensive.

PH. 40. "Several of the more permanent streams were bent, at times, into irregular arches of different curvatures and positions."—Dr. *Langwith.* Phil. Tran. No. 399, p. 301.

Exp. These irregularities are the natural result of the great variations often produced in the atmosphere.

Communication of Magnetism.

PH. 41. If a bar of iron be placed in a position nearly vertical, and suffered to remain a long time in that position, it will acquire magnetism; thus, the vertical iron bars of old buildings, and fire irons which have been long in use, are found to be magnetical.

Exp. The general electrical state of the atmosphere is

positive, (*ph.* 10 and 11); therefore, the electric fluid, and other ethereal matter, will descend towards the earth along any vertical bodies, which can transmit it better than air; and since, as explained *ph.* 10, 11, 12, 13, and 18, currents of ethereal matter are continually flowing in the upper parts of the air in spiral lines from east to west, inclining northward, and descending, it is evident that these currents will tend to cut and traverse any vertical conductor in planes nearly perpendicular to its length. Now the magnitude of the spherules, and forces of the atoms or particles, which compose some conducting bodies, may be such that they shall be susceptible of receiving and retaining the impressions of the above mentioned currents to a certain depth on their surfaces, and be forced by its pressure so closely together, as to intercept its deeper penetration, and its farther progress in a direct line, and particularly this may be the case with iron, and ferruginous bodies. The phenomena of magnetism indicate that this is so in fact; hence the general effect of the action of the ethereal matter, which is flowing round the globe of the earth, descending from east to west in spirals from the south northward, will be to cut fine channels, or passages, downward, inclining to the west, and chiefly on the south side of this vertical iron bar; for, on account of the direction in which the current strikes it in its course, it will be cut most completely, and to the greatest depth, on the south side; this effect, combined with the general tendency of the electric fluid to pass downward along the bar, will produce a channelled course in a spiral form, round the bar downward, evidently so as to pass round the bar from the east, first on its south side, and thence to the west, and by north to the east, thus proceeding till it passes off at the bottom of the bar; again, the atoms composing the surface of the

iron, having, in process of time, become fixed in the positions, and the arrangement thus generated, will convey a current of ethereal matter in the same channelled course, even when the bar is moved to another situation, where ethereal matter in motion has access to its surface. Let AB, *fig.* 81, represent the vertical iron bar, E the east, and W the west side, the front which is seen in the figure being the north side; then it is manifest, that since the action of the passing ethereal matter will tend to cut, and channel the surface nearly in the horizontal lines on the north and south sides, but most of all on the south side, because the current is moving northward, it must needs happen, that since electric fluid is admitted down AB, and not freely along it in one line, or through its substance, it must take its passage first on the most complete channels on the south side, and passing round by W, will find an easy passage on the north side, as shewn by the arrow heads, and round to the east again: and thus it will in time form a fine spiral path, as represented in the figure, excepting that the spirals are to be supposed much closer, imperceptible to the eye, and separated, especially in certain parts, only by indefinitely small intervals. It is manifest that the same effect must take place whatever be the shape of the bar; that is, whether it be round or square, or of any other form.

Now if the iron rod stand in that position for a great length of time, it may be easily conceived, that from the continued course of the current, and the gradual action of the air and moisture, the channelled spiral passage in the bar becomes in some degree fixed; and when the rod is moved from its vertical position, it will still transmit such ethereal matter as strikes or presses on it, in the path of these spirals, rather than in any other; for the atoms of the iron on its surface are now so fixed, and their sphe-

rules so disposed or arranged that they conspire to facilitate the current in that direction, and to oppose it in the contrary one; hence, if this rod be freely suspended, and at liberty to move by a very small force, it will assume a direction such that the channels of the spirals, or the plane of their directions, shall coincide, or nearly so, with the current of ethereal matter to which they are exposed; and since such a current is moving continually from east to west, (*ph.* 10 and 11), it follows that the channels of the spirals in the bar will take that direction, and consequently, the bar itself must take a direction towards the north and south, and it must possess therefore this property of the magnet.

Obs. The magnet above described I have ventured to denominate a north needle, because it is such as is formed by position in the northern hemisphere. A needle formed similarly by position in the southern hemisphere would have the spirals the contrary way, as shewn in *fig.* 82; this necessarily follows from the account given of the formation of the north needle, or magnet.

Ph. 42. The magnetical rod or needle, when freely suspended, does not point exactly towards the geographical pole of the earth at most places, but to a point not far from it, that is, to a point in the frigid zone which appears to be somewhere north of Hudson's Bay. Hence at different places it has a different declination; the magnetic meridian making a greater or less angle with the meridians of different places.

Exp. As was explained in *ph.* 18, the current of ethereal matter, gyrating about our globe in spiral lines, finds its way to the earth most copiously in an irregular terrestrial zone near the pole, and more completely and more abundantly so at some places than at others in that zone, hence the circulating spirals round the earth will be

deflected, so as in some degree to regard the place of easiest entrance as their pole, and hence the needle will be directed towards that place according to the foregoing explanation, and hence there will be a declination of the needle with regard to the geographical pole, which will be different according to the situation of the places. From *ph.* 33 it appears that there is a magnetic north pole of the earth somewhere in the neighbourhood of Hudson's Bay.

Ph. 43. That end of the iron rod which was downward, *ph.* 41, is its north pole, or the end which points to the magnetic north, when it is freely suspended,

Exp. For let the rod AB, *fig.* 81, be removed from its vertical position, by which it was rendered magnetical, and let it be freely suspended horizontally so that the end B may be directed towards any part in the NE, or NW quarters; then the current of ethereal matter revolving about the earth in spiral lines (*ph.* 10 and 18), proceeding northwards, and tending downward to the earth, will meet the eastern side of the rod or needle, and in consequence of its channelled course formed as described *ph.* 41; it must descend on the eastern side, passing under and rising on the west side of the rod, so that a spiral current will be produced through it from A to B, and this accords with the eastward and downward course of the earth; the planes of the spirals must therefore be placed in the direction of that current, which being at right angles to the magnetical meridian, the rod itself will therefore take its position in the plane of the magnetic meridian, and evidently, since the spirals in the rod tend downwards inclining to the end B, that end must be directed with the current towards the north. If the end B had been placed so as to point any where to the SE or SW quarters, the current round the rod must rise upwards on the eastern side, contrary to the direction of the terrestrial current,

which in this case meets it on that side, therefore the point B could not be directed towards the south, hence in all cases the end B, which pointed towards the earth, while the rod, in its vertical position, was converted into a magnet, must point towards the north when suspended horizontally. The same would evidently be true if the rod were suspended any where in the southern hemisphere, for still the terrestrial current meets it on the eastern side descending. All this will be exactly understood from a due attention to *fig.* 81, which is so represented, that the spectator is supposed to be north of it, looking on its north side.

Ph. 44. If an iron rod were placed vertically for a long time in the southern hemisphere, in some high latitude, it would become a magnet. NB. I am not aware that this has been verified by experiments, but there can be no doubt of its being a fact, it might easily be ascertained sufficiently, if any person would place a long bar of soft iron vertically in such latitudes, and try if it would attract iron as a magnet while in that position.

Exp. This is similar to *ph.* 41, and is to be explained after the same manner, the needle thus formed I call a south needle: *fig.* 82 is intended to represent the course of its spiral channels formed by the action of the terrestrial current.

Ph. 45. The end of a south needle which is downward, while it is forming in its vertical position will point to the south.

Exp. This may be explained in the same manner as *ph.* 43, having regard to the south instead of the north pole, and from that explanation this phenomenon will be easily understood.

Ph. 46. The needle, if it be suspended from its center of gravity before it is magnetised, and free to move, will,

when rendered magnetical, take a position inclined to the horizon more or less according to the situation of the place in respect of the magnetic pole of the earth, at London the inclination is about 70° below the horizon toward the north.

Obs. Iron may be rendered magnetical in various ways besides that of position, as will be shewn.

Exp. Since the ethereal matter, which revolves round the earth, regards the magnetic pole as the center of its gyrations, and at the same time tends to enter the earth continually as it passes along according to the preceding explanations, it follows, that it will tend to enter the earth in a direction still more and more vertical, as the plane is nearer to the magnetic pole, and it follows evidently from what has been advanced, that the needle freely suspended must take this direction.

Sch. This line which the needle assumes is called the direction of the dipping needle, or the magnetic axis of the needle, or magnet, and a plane at right angles to this axis is called its magnetic equator.

Ph. 47. When a long bar of pure soft iron is placed in the natural position of the needle, that is, in the direction of the dip, it speedily becomes magnetical, its upper end being a south, and its lower end a north pole, but when removed from that position it speedily loses its magnetism, and if placed again in the magnetic line with its ends in the opposite direction, it again becomes a magnet with its poles changed, that is, the end now downward becomes the north pole.

Exp. Iron being admitted to be susceptible of suffering the ethereal matter to penetrate its surface, but to a very small depth only, we conclude, that when in a proper position as above explained, it must happen that pure soft iron will most readily admit of the above stated disposi-

tion of its superficial atoms, and consequently most easily have this arrangement disturbed, which circumstances will account for the fact, since it is easy to conceive that if iron be susceptible of the suitable arrangement of its atoms, soft iron will very readily receive and lose that arrangement.

Ph. 48. Iron rods are rendered magnetical, if scoured, hammered, filed, bent, or twisted, while in or nearly in the position of the magnetic axis, or if dropped vertically on a hard body the same is effected.

Exp. The iron becomes magnetical by being placed in the magnetic axis as in the last phenomenon, and this magnetism becomes more fixed by the operation of rubbing, &c., while under this influence, since such operations make the parts of the surface vibrate, and cause the magnetism to enter deeper, and at the same time more firmly fix the atoms of iron, which compose the surface, in the position they have taken, and hence the rods do not very speedily lose their magnetic virtue.

Ph. 49. If the rods rendered magnetical, as in the last, have the same operations performed on them, while they are held in the magnetic equator, they lose their magnetism.

Exp. While in this position, the earth's magnetism tends to pass at right angles to the spiral current, already fixed in the iron rods, and the operations made on the rods produce vibratory movements in the atoms of iron, and their atmospherules, and hence the earth's magnetism easily effects a new arrangement, and thus the magnetism of the rods is destroyed.

Ph. 50. Iron rendered red hot, and quenched in water, while kept in the magnetic axis, becomes magnetical.

Exp. During the quenching of the iron considerable vibrations must be produced among its particles, hence

the magnetic arrangement is readily produced, and the position of the atoms become fixed by the hardening of the iron when quenched in water.

PH. 51. Hard iron or steel acquires the magnetic virtue with much greater difficulty than soft iron, but retains it much more firmly and constantly.

Exp. This will follow from the more firm and fixed position of its atoms, for this resists the acquisition of the proper arrangement of channelled spirals on the surface, but when this resisting force is once overcome, the spiral channels produced in the magnet are more firmly maintained, so that in whatever position the magnet is afterwards placed, the ethereal matter, which strikes it, is carried round forming a kind of vortex entering it at the southern pole, and going off at the other pole. Magnets in which the magnetic virtue is fixed with great firmness are called permanent magnets.

PH. 52. A permanent magnet, not fully saturated with the magnetic virtue, if hammered while in the position of the magnetic axis, has its power increased, if its south pole be situated upward, but diminished if its north pole be upward.

Exp. Under the action of hammering its parts are in a state of vibration: and while in this state, if its south end be upward, its position is that which favours the formation and deepening of the spiral channels round the surface of the magnet, and thus increases its virtue, but if its north end be uppermost, the effect is the reverse, the action of the terrestrial current being opposed to that already formed, and therefore tends to produce spirals in the contrary direction, and thus to weaken the magnet.

PH. 53. A rod of hard iron, or steel, 3 or 4 feet long, held vertically and struck at its lower end, becomes magnetical.

Exp. The foregoing explanations will account for this phenomenon, and for similar methods of giving magnetism to a body placed in the magnetic meridian.

Ph. 54. There are no known bodies susceptible of magnetism in any sensible degree, except iron, nickel, and cobalt.

Exp. The exhibition of the magnetic power requires, as above shewn, a particular disposition in the superficial parts of the body for admitting the magnetic virtue to proceed down its surface in the way requisite to exhibit magnetism, *viz.* such that it cannot advance far in a direct line; and hence a particular magnitude and force in the atoms composing that body are requisite, and therefore it is not to be wondered at, that the majority of bodies should be incapable of exhibiting this virtue: in some conductors the fluid may be transmitted merely over the surface, in others through the interior substance; but in such as admit of magnetism in a sensible degree it must be capable of entering the surface to a very small distance, and, by pressing, or crowding the atoms of the body in its course together, incapable of making its way in a straight course, and this condition appears to belong to few bodies.

Ph. 55. Many substances combined with iron will render it incapable of becoming magnetical; thus a very small quantity of antimony will render iron unfit to receive magnetism.

Exp. The compound is a new body, whose particles cannot take the required arrangement by the operation of the ethereal matter gyrating about the earth; such an effect of the combination may be easily admitted.

Ph. 56. Iron and nickel, if quite pure and ductile, instantly receive and lose magnetism, but by pressure, torsion, or hammering, they take magnetism with more

difficulty, and retain it more strongly. The same takes place if with the soft iron or nickel a small portion of carbon, phosphorus, arsenic, or brass, be combined, but these substances combined in too great a quantity prevent the power of acquiring magnetism altogether.

Exp. These facts are the natural consequences of what has been advanced on this subject, and hence require no farther explanation.

Ph. 57. When a short bar, AB, *fig.* 76, of hard iron or steel is placed lengthwise in contact with, or very near to a very powerful permanent magnet, SN, for a considerable time, it becomes a permanent magnet. If N, (*no.* 1), be a north, and S a south pole of a north magnet, then in the bar AB the end A, contiguous to N, will be a south, and B a north pole of the new similar magnet AB.

Exp. The ethereal fluid, whether electric fluid, caloric, or light, or all of these, has by some of the means stated in the preceding explanations, or by other means, obtained a freedom of passage through the magnet SN, in the spiral channels round its surface to a small depth in that surface; hence in whatever position SN is placed the ethereal fluid, which, as has been shewn, is continually revolving round the earth, and entering its surface, on striking or meeting with SN will find a rapid passage, at the parts of it towards the extremity S, to enter the surface, and at the parts towards N to escape from the surface, now this ethereal matter, continually falling on the magnet SN, will consequently produce a continual current round it in the spiral channels, entering at S, and leaving it at N, and this will cause the vertical current to extend to some distance in the air round SN, being carried in this revolving motion from the part S towards N, this gyrating current will therefore necessarily act on AB, tending to produce similar spirals, the ethereal matter

entering at A and escaping at B, and thus AB in a sufficient time becomes a magnet.

Ph. 58. The more powerful the magnet, SN, *fig.* 76, is, the more speedily and completely will AB be magnetised.

Exp. The effect must follow the proportion of the cause, and hence the reason of this is evident, since in the stronger magnet the ethereal current is greater and more rapid.

Ph. 59. If AB, *fig.* 76, be a bar of soft iron, it soon loses its magnetism when SN is removed.

Exp. The spiral channels are easily defaced or deranged in the soft iron, which fully accounts for the fact, and this agrees with *ph.* 47, where the magnetism is produced by the terrestrial current.

Ph. 60. The bar AB, *fig.* 76, is more completely and speedily magnetised, when SN and AB are both placed in the magnetic axis, with the end S uppermost.

Exp. This is agreeable to the former explanations, for in this case the earth's magnetism coincides with that of the magnet SN, and therefore increases its power, and likewise conspires with it in producing the magnetism.

Ph. 61. If *a, b, c, fig.* 77, be short bars of soft iron applied as in the figure to the magnet A, they are magnetical while attached, but lose their magnetism when separated.

Exp. The first bar becomes magnetical according to *ph.* 57, 58, and 59, and very rapidly, because it consists of soft iron, and this in like manner magnetises *b*, *b* magnetises *c*, &c., and when removed they speedily lose their virtue as shewn in *ph.* 47 and 59.

Ph. 62. If the bars *a*, *b*, *c*, be of hard iron or steel, they receive the magnetism with more difficulty, but retain it more firmly, and the ends towards A are all south poles, and the others north poles.

Exp. The explanations of 51, 57, and 61, will shew the reason of this fact.

PH. 63. If the bar AB, *fig.* 76, be placed between two magnets with their unlike poles towards each other, that is, if another magnet, similar to SN, were placed in the same line with BA and SN, with its south end near B, the bar AB would be sooner and more completely magnetised.

Exp. For in this case the ethereal matter, revolving about AB, would find a more ready and regular exit at B to the other magnet, than into the air, and thus the effect would be greatly increased: for either magnet alone would produce the same kind of magnetism in the bar.

PH. 64. If the additional magnet had been placed with its north pole towards B, and near it, the bar AB would not receive magnetism so easily, nor would it receive its polarization in the same manner.

Exp. For in this case there is a tendency to produce two south poles in AB one at each end.

PH. 65. When the bar *a b*, *fig.* 78, is very long and presented to the magnet A, it is found to obtain several poles, thus *b* is a south pole, and *a*′ a north pole; again *b*′ is a south, and *a*, a north pole; and there may be several alternations according to the power of the magnet A, the length of the bar *a b*, and its degree of hardness.

Exp. The ethereal matter does not penetrate iron with perfect freedom, and with less freedom as it is less pure and soft, as shewn in the preceding phenomena, since in most cases the iron must not only be in a proper position, but its parts must be put into a state of vibration by some action on it, such as hammering or the like, hence in the act of magnetising, the progress of the ethereal matter pursuing its way, as before explained, from *b* towards *a*, is continually impeded, and the more so as the iron is harder, or the magnet A less powerful, so that in many

cases its progress will be arrested, the atoms of the iron being so pressed together as to serve for a barrier to its course, it will therefore begin to escape somewhere, as suppose at a', finding more easily a passage without the surface of the iron, than within it, but again at b' where the atoms of iron have not been thus affected or pressed together, the ethereal matter will again enter, being admitted to move in it with more freedom than in the air, and again in like manner they will escape at a, and evidently there may be several such changes according to the circumstances, espeially in bars of great length.

Obs. These successive poles are called consequents.

Ph. 66. The harder the bar ab, *fig*. 78, the more susceptible it is of consequent poles.

Exp. This arises from the greater difficulty, which there is in giving magnetism to hard iron, (*ph*. 51), hence the distance a' from b will be less than in a soft bar.

Ph. 67. In whatever way we attempt to magnetise an oblong bar, it will receive the virtue only lengthways.

Exp. From the resistance which iron affords to the passage of ethereal matter in its surface, it cannot penetrate it far in any one given direction, therefore not in a longitudinal direction, it will therefore tend to verge off at the sides, and cut the bar transversely, so that the tendency to pass along the bar, if it take place at all, will be in spirals traversing obliquely, and advancing lengthways only according to a spiral course from one end towards the other, as shewn in several instances above.

Ph. 68. The two poles of a magnetised bar are not precisely at the extremities of the bar, but at some small distance from the ends.

Exp. For the ethereal matter, while the bar is receiving magnetism, presses forward from the end which receives it, making the spiral considerably oblique, but this

motion forward is resisted by the opposing atoms of the iron, (*ph.* 51, 57, 65, 67, and others), hence the spiral channels become continually more nearly coincident with planes perpendicular to the axis of the bar, and are closer together and deeper cut, where this occurs will be the place of greatest concentration of the fluid at the end which the fluid enters, and will there constitute one pole at a small distance from that end, at this point the ethereal matter enters most copiously; it penetrates less freely and more on the superficies at a greater distance because of the compression of the atoms of the iron and falls obliquely from that point, till at a greater distance it ceases to enter, and begins to escape, and in greater abundance at a certain point, as at the consequent pole *a*′, in *ph.* 65, and this point where there are only two poles will be at a small distance from the farther end, because the bar will admit the current with more freedom longitudinally, very near the end where it goes off, than at a remote distance; hence the pole where the fluid finds its exit in planes nearly perpendicular to the bar will be at some small distance from the farther end.

Obs. The current of ethereal matter, produced and propagated through the magnet, will evidently cause a current of ethereal matter in the circumjacent air, or surrounding space, and the manner of its revolving round the magnet through the air, will be considerably affected by the positions and course of the spirals in the metal as shewn in this phenomenon. This may be illustrated by the help of *fig.* 85. Let S be the south pole, and N the north pole of a north magnet, cylindrical in form, then the ethereal fluid enters at the end S, and is carried off at the end N; but it enters and goes off in different positions to the bar SN, as explained in the preceding phenomenon, from an attention to what is advanced

in the explanation it will be seen, that the circumgyrations in the air must have a particular reference to the poles S and N, so that at the end they will be cylindrical corresponding with the cylindrical magnet SN; at a very small distance from the end they will form an acute angled cone *cd* S, whose sides meet the surface of the magnet at *r* and *m*: nearer the pole S the revolutions are in an obtuse cone *ab* S, whose sides meet the magnet nearer to S; at S the gyrations are at right angles to the axis of the magnet as in *ef*, and similarly they are inclined to *ef* on the other side of the pole S as shewn in the figure, till they become cylindrical again in the middle near *t*, after this the ethereal matter makes its escape, and gyrates in the air, going off in positions similar, in respect of *pq*, to those in which it enters in respect of *ef*; when the magnet is of some different shape the position of these circumgyrations in the air will be in some degree more or less modified by that circumstance. It is manifest that similar observations will apply to a south magnet.

Ph. 69. The harder the magnetised bar is, the nearer will its poles be to the extremities of the bar, when it is free from consequent points.

Exp. For the harder the bar is, with the more difficulty will it be penetrated by the ethereal matter, which therefore will reach to a less distance while it proceeds in a direction nearly perpendicular to its length; and it will approach nearer to the other end before it makes its exit in that manner, because it cannot leave the bar in a longitudinal direction to so great a distance from the end.

Ph. 70. If a magnet be cut through the axis, the two parts will become two magnets, having those ends, which were in contact, poles of the same name.

Exp. The parts separated have already the atoms of three sides in a suitable arrangement to produce this

effect, hence the ethereal matter, striking on these parts, readily finds its way through the newly exposed surface at the section, and the two parts will evidently in a short time become magnets with their poles as stated.

PH. 71. If a magnet be cut into two parts in a direction perpendicular to its axis, each part, some time after the separation, will become a magnet; the polarity of the parts before in contact will now be contrary poles.

Exp. Let A*b* and *a*B, *fig*. 79, be the parts separated at *b* and *a*, before in contact, of which the part A is the south pole, or that at which the magnetism entered before separation, it is manifest that now the ethereal matter will still enter readily at A, and must therefore pass out towards the end *b*, and in a short time A*b* will become a magnet having *b* for its north pole. Again the disposition of the superficial atoms of *a*B are such as to admit the fluid to move in its former course, that is, to pass off at B, and hence in a short time it will enter most at the parts near *a*, while it still readily finds its exit at B, and thus *a* becomes a south pole.

PH. 72. When the magnet is fractured as in the last phenomenon, its center at first is near the fractured end, but in time it approaches near the middle of the part.

Exp. This happens because at first the ethereal matter does not escape with freedom at *b*, in A*b*, nor enter freely at *a* in *a*B.

PH. 73. If the like poles of a strong and weak magnet be placed together, the polarity of the weak one will be first diminished, then annihilated, and at last reversed.

Exp. The effects of the magnets on each other at first will evidently tend to weaken each other's power, since the convolutions of ethereal matter are in contrary directions, and meeting each other: hence in time the

stronger magnet will change the arrangement of the superficial atoms of the other, and destroy its magnetism, while its own power is diminished, but not destroyed; after this it will, in the other magnet, generate new spirals in the direction of those on its own surface, as explained *ph.* 57, and following, and will itself also, by the flowing of the current, again recover the force, or part of the force it had lost by the action of the weaker magnet.

PH. 74. If a small magnetic needle, moveable on a pivot, be placed between two magnets, so that the heterogeneous poles of the needle and magnets be near each other, the needle after some oscillations will take a quiescent position between them.

Exp. For the gyrations of the ethereal matter through the magnets and needle being the same way, the needle will vibrate till it corresponds with the other in force, and will then soon be fixed in a quiescent position between the poles of the two magnets.

PH. 75. If a slender good magnetic needle be suspended by a short fine thread, and held near the pole of a strong magnet, or between the contrary poles of two powerful ones, so as not to touch them, it will be thrown into a violent vibratory motion, having the appearance of a motion produced by a fluid whirling round it, till after some time the needle becomes quiescent.

Exp. This sort of motion is exactly conformable to those deduced from the foregoing phenomena, and tends to establish the explanations, the quiescent state ought to succeed when the needle has acquired the full state of magnetic power, which the magnet or magnets can communicate to it in that situation; the vortical motion will be understood from consulting the observations at *ph.* 68, where it is explained by the help of a figure.

PH. 76. If one end A, *fig.* 80, of a magnet be drawn

along a needle or rod *ab* of hard iron or steel several times in the same direction, the needle or rod will become a magnet, and the pole applied will give a contrary polarity to the end of the needle last touched. Thus if A be the north pole of AB, and the magnet be carried from *a* to *b* either in an upright position, or a little inclined, the end *b* which it leaves will be a south pole. This is called the single touch. The magnet AB should be drawn several times along *ab* in the same manner and direction.

Exp. It is evident that the circumvolution of the ethereal matter about the pole A will, as AB passes along, tend to cut the surface of *ab* in a similar manner, thus if A be the north pole of a north magnet, the fluid is passing from B to A in spirals from right to left on the nearer side as we look on the figure, in the plate placed before us, it descends on the opposite side, and hence it will pass down on the farther side of *ab*, and rise on the nearer, and *a* becomes a north, and *b* a south pole of a north magnet. But if A be a south pole of a north magnet the ethereal fluid is entering at A, descending on the nearer side and rising on the other, hence it will descend on the nearer side of *ab*, and rise on the opposite, and *a* will become a south, and *b* a north pole.

Ph. 77. If two or more equal magnets, with their like poles conjoined, be used together in the manner above described, to magnetise a bar, the same effect is produced more speedily and completely.

Exp. For both the united magnets act in the same way on the bar, and produce the effects of one stronger magnet.

Ph. 78. If the magnet be drawn over the bar in the opposite direction, it will destroy the magnetism which it had before communicated.

Exp. This is easily seen, since it now tends to give to

the bar a contrary polarity, that is, to cut a spiral course in the contrary direction.

PH. 79. It is very difficult if not impossible to communicate the magnetic virtue uniformly by the method above explained, or perhaps by any other method.

Exp. When the bar to be magnetised is not of an uniform texture, it has a tendency to receive consequent points when the magnet is applied, (*ph.* 65 and 66), and since it is very difficult to procure bars of an uniform texture and degree of hardness, a perfect uniformity in the magnetism of the bar is not to be expected, especially if the magnet rest longer on one point than on another, for there is always a tendency to produce a pole where the magnet is stationary, as must be evident from the explanations already given.

PH. 80. Bars of steel, which have been well hardened, and softened down in the middle by placing the bar on a red hot iron till the blue colour which arises disappears, about an inch at each end being left as hard as possible, make the best, most regular, and permanent magnets.

Exp. For the tendency of the bars in general is to have their poles near the ends of the bar, (*ph.* 68), but if the middle be hard a consequent point is often formed there from the resistance of the hard metal; this resistance is greatly diminished by softening the middle, hence consequent points are avoided, and the two contrary poles will be near the extremities, and because of the hardness there will be more fixed: the softer part in the middle more freely transmitting the current adds to its efficacy.

PH. 81. If two magnets, SN, N'S', *fig.* 83, and 84, be placed with their unlike poles on a bar *sn* of hard iron or steel, near its middle at a small distance from each other, the bars being parallel and upright, or inclined either way, and then slided uniformly backward and for-

ward the whole length of the bar, not passing either of its ends, and beginning and ending near the middle, the same relative position of the two magnets being constantly retained, the bar will receive a strong degree of magnetism, which will be farther increased by performing the operation on its other side, the disposition of the poles remaining the same. The poles of the horizontal bar will become poles contrary to those which are nearest them while the operation is performed, and consequently which last touched them. This is called the double touch. The magnets should be taken away in their perpendicular direction.

Exp. The ethereal matter, descending spirally from right to left in SN, on the side facing us in the figure, and ascending from left to right in S′N′, thus passes, as far as regards the spirals in the same direction between the magnets, that is, towards us as we look at the figure, and from us on the exterior sides; now the revolving matter will find an easier passage from N and to S′ around the part of the bar *sn*, which lies between them, than in any other way, since there the currents of both magnets are conjoined, therefore the bar *sn* will become channelled from N to S′, and as the magnets are slided through the whole length, the bar will become strongly magnetised, and since the current flows towards us on the top of *sn* between the magnets it will descend on the side facing us, and *sn* will have its north pole at *n* and south pole at *s*. This method was invented by Mr. *Mitchel*, and is called the method by the double touch.

Ph. 82. If the poles of the magnets be reversed, or which is the same, put each in place of the other, and then drawn over the magnetised bar, its magnetism will be destroyed, and by continuing the process, the bar will

receive magnetism in the contrary order, that is, with its poles reversed.

Exp. The reason of this is at once seen from the preceding explanations, since the current, which gives the magnetism, now flows in the contrary direction.

Ph. 83. In magnetising by the double touch, as in *ph.* 81, a particular distance is necessary for producing the greatest effect, for if the two magnetic bars be in contact no magnetism, or but very little is generated, and if the distance between them be very great the effect is very small; hence there is a particular distance, at which the magnets will communicate the virtue most completely.

Exp. When the two magnets are in contact with their contrary poles united, the ethereal matter which descends along SN, *fig.* 83, will ascend along S′N′ from pole to pole, and thus the magnets will neutralize each other, and can produce but very little or no sensible effect on *sn*; also when SN and S′N′ are at a very great distance from each other, the current between them is less condensed, and the effect proportionally diminished, but at a certain distance both currents act with full force, in which case the effect is a maximum.

Ph. 84. The method of magnetising by the double touch, as in *ph.* 81, when the two magnets are upright, is apt to produce consequent points, or alternations of poles in the magnetised bar, and other things the same, this effect will be greater or less according to the distance and inclinations of the magnets, and the regularity of the motion in sliding them along.

Exp. The reason of this fact will appear, when we consider that while the magnets remain at one part of the bar, that part from N to S′, *fig.* 83, becomes a separate

magnet, and this will be more permanently so, if *sn* be very hard; hence this method of the double touch tends to produce alternations of poles, especially if the motions of the magnets be irregular.

PH. 85. Instead of keeping the magnets SN and N′S′, *fig.* 83, parallel to each other, as in *ph.* 81, let the upper ends be placed in contact, and the lower ends kept apart by means of a pin placed between them, or otherwise, then by gliding them backward and forward as before, not passing either end, the bar *sn* will be magnetised as before. This variation in the method of *ph.* 81, was employed by Mr. *Canton.*

Exp. This is the same as *ph.* 81, as far as it relates to the magnetising the bar *sn*, the magnets acting in the same way at NS′, but probably the effect is greater, because the same ethereal current which ascends along S′N′, will descend down SN, the poles N′S being joined, and descending in SN, it will flow, as shewn in *ph.* 81, round *sn* between the magnets and ascend in S′N′, and this free circulation of the ethereal matter will tend to strengthen the current.

Obs. It will be recollected that the current itself in any magnet is kept up in consequence of the ethereal matter flowing round the earth as already clearly shewn.

PH. 86. Mr. *Epinus* proposed another variation in this process. Instead of bringing the two upper poles SN′, *fig.* 83, into contact, he made them incline the contrary way, very much from each other, so that each magnet should make a small angle about 15° or 20° with the bar *sn*, being such a position as shewn by the dotted lines in *fig.* 84, and still keeping the lower ends at a small distance as in *ph.* 81, he slided them backward and forward, as before described, and thus magnetised the bar *sn*.

Exp. The bar *sn* will evidently receive magnetism for the same reasons as delivered in *ph.* 81 and 85.

Ph. 87. But this method of *Epinus* is more liable to produce consequent points than that of *Mitchel,* (*ph.* 81 and 84), which renders it less proper.

Exp. Conceive the magnets SN and N′S′ *fig.* 83, inclined as stated in *ph.* 86, *viz.* with N′ leaning towards *n,* and S towards *s,* see the dotted lines in *fig.* 84; then it will be seen that while the current of ethereal matter is flowing in both the magnets towards us between them, it is moving from us on the other sides, hence the magnetism will be produced in *sn* as before by the ends, and near the ends N and S′, but at a small distance higher these sides are near enough to *sn* for it to be in some degree affected by the currents in the opposite direction, and hence consequent points are very likely to be produced, for when N and S′, are near *s,* the effect which has been produced towards *n* is disturbed by the contrary current in S′N′, and when N and S′ are near *n,* the effect which has been produced towards *s,* is disturbed by the contrary current in NS, since as just shewn, it is moving between them, from us in SN, and towards us in *s*N in the angle *s*NS. Hence this method is inferior to that of *Mitchel* or *Canton.*

Ph. 88. To remedy the inconvenienee of the method adopted by *Epinus,* (*ph.* 86), M. *Coulomb* brought the two ends of the magnets NS′, *fig.* 83, in contact, and placed them on the center of *sn* inclined from each other, as in the method of *Epinus,* and shewn by the dotted lines in *fig.* 84, but instead of carrying them backward and forward on the bar *sn,* he drew them from each other towards the opposite ends, that is NS towards *s* and N′S′ towards *n,* till they were brought to a small distance from their respective ends, and then commenced the friction anew;

always proceeding from the middle. This method of the double touch is found to give the most uniform magnetism to needles or bars, producing but two poles near the extremities of the bar *sn*, especially if the bar be hardened, and softened down again to a proper degree in the middle, as stated in *ph*. 80, the ends being left hard.

Exp. It is manifest that the magnetism will be produced by both the magnets as they are drawn along, also the disturbing force, mentioned in *ph*. 87, is here reduced to almost nothing, since where it takes place the magnets are removed considerably from the bar *sn*, and since there is always in the bars a tendency to form only two poles, in this case such tendency is not opposed but promoted, the effect will be such as to produce magnetism in *sn* free from consequent points. This will be still more effectual if *sn* be very hard at the ends and soft in the middle, for while the magnets are separating, and at some distance, the magnetic current will freely and readily gyrate about the intermediate space of the bar *sn*, because of its being rendered softer than the other parts.

Ph. 89. If the bar *sn*, *fig*. 83, to be magnetised, be large, it is found to be advantageous to place it on two other magnetic bars in the same line; the end *s*, which is intended to be a south pole, should rest on a north pole of one of those magnets, and *n* on a south pole of the other.

Exp. It is evident that those magnets on which the bar rests tend to communicate magnetism in the bar similarly, and hence greatly conduce to promote the desired effect.

Ph. 90. When two bars are to be magnetised, place them parallel to each other, as *sn* and *n's'*, *fig*. 84, and

against their extremities place the parallelopipeds A and B of soft iron, the whole forming a rectangular figure; then apply two magnets to magnetise one of them according to any of the four methods by the double touch: *viz.* with the magnets parallel, as shewn in *ph.* 81, by SN, N'S' according to *Mitchel's* method, or by joining them at the top SN', as in the variation by *Canton*, (*ph.* 85), or by inclining the magnets into the position shewn by the dotted lines, and proceeding either by the method of *Epinus*, (*ph.* 86), or *Coulomb*, (*ph.* 88). This operation will produce a degree of magnetism in the other bar *n's'*, having its poles in the contrary order to those of *sn*.

Exp. When *sn* is rendered magnetical, the current of ethereal matter, which now revolves about it in spirals, *towards* the person who views it from the east, on the upper side, and proceeding towards *n*, as before explained, will pass along the soft iron B more readily than it can find its way through the air, and consequently falling under the soft iron, it will rise above it and tend to gyrate in the direction on the upper side, as shewn by the arrow from B; in like manner there will be a tendency to pass over to *s'n'*, proceeding according to the direction of the arrow on the upper surface of *s'n'*, in like manner the ethereal matter entering *sn* will be received through the medium of the soft iron B, rather than immediately from the air, which will therefore have the direction as shewn by the arrow on it; hence *sn* being magnetised, there is a tendency to produce a current through the system, rendering *s'n'* magnetical, with its poles as the letters denote.

PH. 91. After a certain number of strokes have been applied on the upper surface of *sn*, it is to be turned over without changing the disposition of its poles, and the operation must be repeated on the other surface. This

being done, the magnets are to be applied similarly to *s′n′* with their poles reversed, and the operation performed as on the former bar, by this means a strong degree of magnetism will be communicated to both the bars. It is advantageous to have the bars and the magnets of the same size.

Exp. What has been advanced in *ph.* 90, with those to which a reference is there made, will fully shew the reason of the action of the magnets in these operations.

Ph. 92. If the magnets SN, N′S′, *fig.* 84, be carried round, passing off from *sn* to B, and from B to *s′n′*, &c. the effect is produced sooner than by sliding them backward and forward in the usual way.

Exp. Evidently this procedure will operate to promote the like effect, and being more regular is likely to produce more uniform and better magnets in less time.

Ph. 93. Strong magnets more speedily and completely communicate magnetism than weak ones.

Exp. This will be clearly understood from considering, that the currents of ethereal matter are in this case more energetic.

Ph. 94. If instead of employing two single magnets, SN or N′S′, *fig.* 83 or 84, two parcels of magnets be used, each parcel equal in number, and having like poles conjoined, the effect is similar, but much greater.

Exp. This will follow because of the conspiring forces of the magnets on each side, which necessarily increases the effect.

Ph. 95. If the magnets employed SN, N′S′, *fig.* 83 or 84, have not their full magnetism, they will give to the bars, which are magnetised, a greater power than they themselves possess.

Exp. For since the passage of the ethereal matter, is

the same way between the magnets, as shewn in *ph.* 81, the current will strike deeper, and give a more effectual magnetism to the bar, than either of them possesses separately, so long as the bar is capable of receiving more; but evidently when the magnets have as high a degree of magnetism as the bar is capable of receiving, the effect cannot be sensibly increased.

Ph. 96. If two bars have but a small degree of magnetism, by means of them the full power may be given to a set of bars, by first magnetising two bars, as in *ph.* 90, and 91, or 92; and then using the two newly magnetised bars to give additional magnetism to the first employed, and so on alternately till they are saturated.

Exp. The reason of this will be quite clear from the last phenomenon, since it will be seen that the bars used give a greater power than either of them separately possesses, and hence the effect is increased by each alternate operation, till the bars are saturated.

Ph. 97. If the bar, to be magnetised, be placed in the magnetic meridian, it more readily acquires the magnetic virtue.

Exp This arises from the magnetism of the earth conspiring with that of the magnet employed.

Ph. 98. In general the power of the magnet is increased by communicating magnetism to another body.

Exp. For during the operation the current of ethereal matter is carried round the magnetised body, and therefore becomes more rapid and energetic, because it has a more free and easy passage than through the air; hence, the power of its magnetism is increased for the time, and permanently, if before the process it were below the point of saturation.

Ph. 99. A bar magnet, if hammered while in a vertical position, or in or near the magnetic axis, has its power

increased, if its south pole be upward, and loses some of its magnetism, if its north pole be upward.

Exp. When struck in this position the atoms of the iron are put into a vibratory state; hence, when the north pole is downward, the earth's magnetism tends to cut the spiral channels more completely and deeply; but in the opposite position it will evidently produce a derangement in the spiral course, and lessen the magnetic virtue.

Ph. 100. The power of a magnet may be impaired by suffering it to remain long in an improper position. Thus if a magnet continue long with its north pole elevated, or if it rest in a position parallel to the magnetic equator, it will be injured.

Exp. The reason of this in the first case is, that the earth's magnetism operates in the contrary direction to that of the magnet, and in the second case it acts at right angles to the plane of the spirals, and thus disturbs the arrangement of the atoms of the magnet.

Ph. 101. Magnets have their power diminished by lying in a wrong position in respect of each other.

Exp. It is plain that their position may be such as to increase or diminish each other's power, since their currents may conspire to proceed in a continued progress, or to oppose each other so as to lessen the effect.

Ph. 102. If a weak magnet be placed in a line with a strong one, and so that their north poles may be in contact, the weak magnet will not only have its power destroyed entirely, but its poles will be reversed, and similarly if the south poles were in contact.

Exp. This will be easily understood from *ph.* 57. Thus if A, *fig.* 77, be a powerful magnet, and *ac* a weak one with its north pole *a* in contact with the north pole of A, *ac* will first be neutralized, and then its poles will be

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reversed, as is evident from several of the phenomena already explained.

Ph. 103. The power of a magnet is preserved by connecting its poles by a piece of soft iron. This is called the armature, and a magnet so furnished is said to be armed.

Exp. The magnetic current which passes off at the north pole, more freely enters the soft iron than the air, and enters the south pole more freely from the soft iron than from the air; much more then does it circulate more freely through the magnet and armature, than through the magnet alone, and this evidently will preserve the magnetic power.

Ph. 104. The method of magnetising a needle by the single touch, *ph.* 78, possesses few or no advantages over the method by simple contact.

Exp. Let A, *fig.* 80, be the north pole of the magnet AB, when A is on *a*, it tends to make *a* a south pole by the action of the current leaving A, and proceeding to enter *ab* at *a*; on the contrary when at *b* it gives to *b* the property of a south pole, tending to reverse that of *a*, (see *ph.* 57 and 76): the only advantage we can conceive therefore in this method is, that the channels are cut across the bar *ab* while AB passes along, and thus the effect is produced sooner than by simple contact; but this advantage is partly counteracted by the greater probability of giving to the bar consequent points, especially if AB remain longer at one place in *ab* than at another.

Ph. 105. If to a needle, or small bar magnet, which has but two poles, one at each extremity, we apply, at a point near its middle, the pole of a stronger magnet, it will produce there a pole contrary to that which was applied, and will thus produce consequent points in the needle.

Exp. The reason of this will be evident from *ph.* 57, 104, and from the several explanations already given.

PH. 106. If *ab*, *fig.* 80, be rendered magnetic to a certain degree of power, and if AB, a magnet, formed of steel or hard iron, but of less power than *ab*, be drawn over it from *a* to *b*, as in the figure, *a* and A being like poles; then part of the magnetism of *ab* will be destroyed, and the virtue remaining will be only as much as could be communicated by AB.

Exp. When A is in contact with *a* it gives it an opposite polarity, and thus it destroys its former power; and by passing along the part towards *b*, it can regenerate only as much virtue as itself is capable of communicating.

PH. 107. This diminution of the magnetism of *ab*, *fig.* 80, would not have occurred if AB had, as above, been drawn only over the half of *ab* to *b*.

Exp. For in this case the current in the first half from *a* is not interrupted but rather increased.

PH. 108. If a bar of hard iron or steel be placed in the magnetic axis, and an electric shock passed through it, it sometimes becomes a magnet, and this effect more easily takes place, if the shock be passed through it transversely.

Exp. The electric shock puts the atoms of the iron into a state of vibration; hence the effect is produced as in *ph.* 48: also the effect is more readily produced when the shock is passed transversely, because, it tends, in this case, to move the atoms of the surface nearly into the position they should have in the magnet, as is seen in the foregoing explanations.

PH. 109. *Van Marum* found, that if the bar were placed horizontally in the magnetic meridian, whichever way the shock entered, the end that was towards the north

acquired north polarity; and if the bar had polarity previously, and were placed with its south end towards the north, its former polarity was always diminished or destroyed, and often reversed. When the bar was standing perpendicularly, its lower end always became a north pole, even if it previously were magnetic, and were placed with its south pole downward.

Exp. All these facts are exactly agreeable to the preceding explanations, and tend to confirm them.

Ph. 110. When the bar to be electrified, as in the last, was placed in the magnetic equator, it never received magnetism, if the shock were passed through it lengthways; but if it passed through it transversely, it frequently received magnetism, and the end which was westward became a north pole.

Exp. The bar being in the magnetic equator, and the shock passed through its length, both the electric matter, and the magnetic current round the earth, tend to pass that way, so that whatever vibrations may be produced in the bar, there can be no transverse passage formed, and the bar cannot become magnetical; but when the shock is passed transversely, the lateral passages are formed, and since the ethereal matter is constantly passing round the earth, towards the west, it will generally find its way, by means of those lateral channels, so as to move spirally over and above its surface from east to west, and hence the end pointing toward the west will become a north pole.

Ph. 111. Lightning will sometimes reverse the poles of a magnetic needle.

Exp. The stroke of lightning is a strong spark of the electric fluid, which may strike the needle in various ways according to circumstances, and hence may in some cases, as will be evident from the two last phenomena, reverse the poles of the needle.

PH. 112. If a slender metallic wire be formed into a spiral or helix by bending it round a small cylinder, or otherwise; and if a steel needle be placed in it longitudinally, and then a few electrical sparks passed through the helix; suppose by connecting one end of the helix with the positive conductor of an electrical machine, and bringing the other end to the negative conductor; the needle will become magnetical.

Exp. Here it is evidently seen that the electric current through the spiral wire must cut the needle laterally, proceeding round in a spiral track from the positive conductor or electrifying body to the negative one, and hence it ought, (*ph.* 41, &c.) to render the needle magnetical.

PH. 113. If the contortions of the helix be in the same direction as represented by the spiral in *fig.* 81, that end of the needle which lies towards the positive conductor becomes the south pole, and the other end the north pole, (see *ph.* 43).

Exp. As shewn in sections vii. and viii. a current of electric fluid passes along the helix from the positive to the negative conductor, and evidently this current will tend to produce the same arrangement in the atoms composing the surface of the needle, as that which was shewn to be produced in an iron bar placed vertically, in high northern latitudes, (*ph.* 41), that is, the needle will become a north magnet.

PH. 114. If the wire be formed into a helix according to the direction of the spiral revolutions marked in *fig.* 82, the extremity of the needle which lies towards the positive conductor will be the north pole, and the other the south pole.

Exp. It will be seen that in this case, the electric current must tend to produce the arrangement of the superficial atoms of the needle just in the same manner as they

would be arranged in a bar standing vertically in high latitudes, (as shewn in *ph.* 45, and the *obs. ph.* 41), that is, the needle will become a south magnet, so that the end situated nearest to the positive side will point north (*ph.* 45.)

PH. 115. If a hard steel bar be made a little warm, and while warm magnetised by the double touch, it will receive the magnetism more quickly, and in a higher degree than if it had been magnetised in the same manner while very cold.

Obs. This fact was suggested by the theory, and I afterward verified it by experiment.

Exp. While the temperature of the metal is a little raised, the proper arrangement of its superficial atoms may be expected to be more easily produced than when it is cold.

PH. 116. If a needle, not magnetised, be suspended at its middle by a thread, so that the thread shall have a vertical position, and if the needle be then magnetised, the thread will still retain its vertical position, and hence no alteration of weight or tendency *towards* the magnetic pole is produced on the needle.

Exp. The action between the iron, and the ethereal matter entering at one end, is evidently equal and opposite to that which occurs between the iron and the fluid leaving it with equal velocity at the other end, hence no deviation of the vertical thread ought to be observed.

Attraction and Repulsion.

PH. 117. The contrary or unlike poles of two magnets attract each other.

Exp. First, Let both magnets, SN, AB, (*fig.* 76, *no.* 1), be north magnets, N being a north and A a south pole. It is evident that the ethereal current leaving SN at the part N, and entering AB at the part A, will proceed in the same direction in both, as shewn by the arrows, and will press on the distant or remote sides of the spirals, both in the magnets and in the air, (see *ph.* 41 and 68 with the *observations*); this will be more clearly understood by looking at *fig.* 85, and supposing another similar one applied to it, as AB is to SN in *fig.* 76. Hence the magnets will be pressed towards each other with greater or less force, as the magnets are more or less powerful, and their distance is less or greater. If therefore A be presented to the other sides of the pole N, it will still be attracted, for, as will appear by *ph.* 41, the ethereal current will press most on the distant sides of the spirals in AB.

If SN and AB were both south magnets a similar explanation would apply.

Secondly, Let one SN be a north magnet, and the other AB, (*no.* 2), a south magnet. Here the currents leave the magnets, the one at N and the other at A, but they pass off at these contiguous poles in the *same* direction as shewn by the arrows, hence since the ethereal fluid goes off in one stream, the current still presses evidently on the distant sides of the spirals in each, and hence urges the magnets together as before; if B had been a north and SN a south magnet, it is clear that the same would hold good.

PH. 118. The like poles of two magnets, placed not very near together, repel each other.

Exp. First, let the magnets SN, AB, (*fig.* 76, *no.* 1), be both north magnets, and N and A both north poles, then the current of SN is going off at N, as shewn by the arrow, and that of BA is going off at A, as would be shewn by the arrow, if the barb had been put at the other end, that is, the current flows in the direction contrary to that pointed out by the arrow, hence the currents go off at the contiguous poles in *opposite* directions, and therefore must produce a pressure on the sides of the spirals which face each other, and consequently the magnets recede, that is, they repel each other. A similar procedure would shew that the two south poles of these magnets would repel each other, because the currents would enter them in opposite directions. In like manner in two south magnets, repulsion takes place between poles of the same name.

Secondly, Let one SN, be a north magnet, and the other AB a south magnet, (*fig.* 76, *no.* 2), N and A being both north poles. Then the current is leaving N in the direction shewn by the arrow, and it is entering A in the direction opposite to that shewn by the arrow at A, that is, it is leaving one and entering the other in *opposite* directions on the *same* side of the magnets, hence the pressure will be on the sides of the spirals which face a line passing between the magnets, and therefore repulsion will be manifested between them. A like explanation will shew that the two south poles would repel each other.

PH. 119. If the two magnets, as in the last phenomenon, be placed with their poles very near each other, the repulsion will be changed into attraction.

Exp. In this case the two opposite currents will, at the place of very near contact, either neutralize each other,

or one of them will prevail so as to make but one current at that part, hence the ethereal matter will there pass off, and relieve the pressure on the sides facing the line, or plane which may be supposed to separate the magnets, and consequently the pressure rests on the opposite sides and produces attraction.

Ph. 120. These attractions and repulsions are manifested in the vacuum of an air pump.

Exp. Since the attractions and repulsions are produced by the actions of the free ethereal matter, which is constantly flowing through the atmosphere, (*ph.* 41), and since this matter can readily pass through most bodies, it will consequently affect the magnets in the same manner, though perhaps not in the same degree, *in vacuo*, as in the open air.

Ph. 121. The magnetic attractions and repulsions are also produced similarly, when any bodies, not susceptible of magnetism, are interposed.

Exp. This arises in consequence of the facile, and uninterrupted passage of the free ethereal matter through substances not magnetical.

Ph. 122. If a very small magnetic needle *sn*, *fig.* 85, so suspended as to move freely in any direction, be presented near the different parts of a large and strong magnet SN, N and *n* being north poles and S and *s* south poles, it will be found that the needle *sn* will take different positions to the large magnet at the different places to which it is presented.

Exp. A little attention to *ph.* 117 and 118, will at once shew the reason of the fact here stated; and the particular situations of *ns* will be shewn in the following phenomena.

Ph. 123. When the needle *sn*, *fig.* 85, is placed oppo-

site to the end of the magnet SN, it will take the same direction and point the *same* way.

Exp. For the direction of the magnet will be determined by that of the current of ethereal matter which meets it, and will be such that the direction of its spiral channels, (*ph.* 41), shall be in that of the current which revolves round it, in consequence of its being a magnet, (*ph.* 41,) which current itself will tend to coincide with any current of ethereal matter, in which it may be placed: also the end, at which the ethereal matter enters the superficial channels, will point towards that part from which the ethereal current has its source, and consequently the other end towards the opposite point. Now when the needle is at the end S, at *sn* the current entering the large magnet SN at the end S, revolves at *sn* in cylindrical circumvolutions, (*ph.* 68, *obs*), and proceeds towards N, hence the needle *sn* will point as in the figure; similar reasons will shew that at *s'n'* it will take the position there represented, since the current has its source from N, and at *s'n'* revolves cylindrically.

Ph. 124. If the needle be placed opposite the center *t*, as at *n''s''*, it will still lie in the same direction, as the axis of SN, but its poles will point to the *opposite* quarters as shewn by *n''s''*.

Exp. The current at the center *t* is also cylindrical round SN, (*ph.* 68, *obs.*), also it leaves SN at N, and therefore *s''* should point that way to receive the current, (*ph.* 41, and 123), and it enters SN at the end S, hence *n''* should be influenced towards that part, (*ph.* 41, and 123), hence it must take the position shewn by *s'' n''* in the figure.

Ph. 125. The positions of the needle when placed near the other parts of the large magnet SN, *fig.* 85, will

be nearly as represented by the little arrows in the figure.

Exp. This will be very manifest, considering the positions *sn*, *s'n'*, and *s'' n''*, explained in *ph.* 123 and 124, with the revolutions in conical surfaces tending towards S at the south pole, and from N at the north pole, as shewn in the observations to *ph.* 68.

Ph. 126. If the freely suspended small needle be carried round the magnet SN, *fig.* 85, it will revolve twice about its center, *viz.* once, while going round each pole.

Exp. How this effect is produced will be seen by keeping in mind the three preceding explanations, and noticing the particular positions of the needle *sn* in the figure, as shewn by the small arrows.

Ph. 127. If a small and slender piece of soft iron, freely suspended, be presented to the magnet SN, *fig.* 85, at its different parts, instead of the needle *sn*, it will be attracted by it, and take different positions, the same as represented by the needle *sn*, also the iron will itself be magnetical, while in these situations, having its poles posited as those of the needle *sn*, and as represented by the small arrows.

Exp. Soft iron easily acquires the magnetic properties, (*ph* 56), and therefore, when in those positions, will acquire magnetism by the circumvolutions of the ethereal matter about SN, as it does by the earth's magnetism, (*ph.* 47), and hence while in these situations will be magnetical, and exhibit all the properties of a small magnet, and (*ph.* 125) will take the positions specified.

Ph. 128. If a piece of soft iron be placed in contact with either pole of a magnet, it will be attracted by it, and if not exceeding a certain weight will adhere to the magnet.

Exp. The iron in contact immediately receives magnetism in virtue of the ethereal matter, which flows over

its surface to the magnet, when attached to the south pole, or from the magnet to it, when joined with a north pole of a north magnet, (*ph.* 56 and 47). Hence (*ph.* 117), it will adhere to the magnet with a certain force.

Ph. 129. While the soft iron is attached to the magnet as in the last phenomenon; the most distant end attracts the same pole of a magnet, as would be attracted by the pole of the magnet, to which the iron adheres.

Exp. This is the necessary consequence of its becoming a magnet, as shewn in *ph.* 127 and 128, the explanations of which it tends to confirm.

Ph. 130. If the piece of iron be removed from the magnet, and its opposite side put in contact with the same pole, it will still adhere, the appended iron is still a magnet, but with its poles reversed, the lower end attracting now the pole of a needle, which before it repelled.

Exp. The reason of this effect, and the change of the poles in soft iron, will be easily seen from *ph.* 56, and the foregoing.

Ph. 131. The attractive power between two magnets depends on their surfaces, being the same whether the magnets be solid or hollow, provided that the surface is the same in both to a very small depth. This follows from the experiments of M. *Daniel Bernouilli.* See Dr. *Young's* Nat. Phil. p. 433. The same is also proved by the experiments of Mr. *Barlow.*

Exp. The action of the ethereal matter, by which magnetism is induced, as shewn in *ph.* 41, and in various others respecting the communication of magnetism, is exerted chiefly on the surface of the iron, which presents some obstacle to its direct pessage through it; hence it is turned off from the direct course, and carried round, only penetrating to a small depth on the surface, hence ac-

cording to all we have advanced on the subject of magnetism, the force ought to be the same, when the surface is so, whether the magnet be hollow or solid: this circumstance therefore favours our explanations.

Ph. 132. When a piece of iron is applied to either pole of a magnet, the magnet will support a greater or less weight, according to the shape of the iron, other things being the same.

Exp. It is evident that the channels, produced by the gyrating ethereal matter, will vary very much with the shape of the iron, and hence a greater or less weight will, in consequence, be supported.

Ph. 133. If a magnet be cut through its axis, the parts which were before in contact, will now repel each other.

Exp. These parts are like poles, (*ph.* 70), therefore they will repel each other (*ph.* 118).

Ph. 134. If a magnet be cut in a direction perpendicular to its axis, the parts, which were before in contact, will now attract each other.

Exp. These parts acquire poles of the contrary name (*ph.* 71), therefore they attract each other (*ph.* 117).

Ph. 135. Smaller magnets have a greater attractive force in proportion to their size, than similar larger ones have. Thus a magnet of half the size of another will support more than half the weight.

Exp. In the smaller magnet the circumvolutions, and spiral channels, formed by the ethereal matter near the acting poles, will be nearly as many as in the larger, because the surfaces, being of the same nature, present equal resistances to its motion, hence the difference will arise chiefly from the length of the spiral, and in the greater, the distance of the acting force is also greater; hence the smaller magnet is more effective in proportion to its magnitude.

Ph. 136. If a magnet be cut into two parts, the parts will support a greater weight than the whole did before separation.

Exp. This follows from the last; also in this case it is evident that a greater surface is brought into action in the parts, than in the whole.

Ph. 137. Heat weakens the attractive power of a magnet.

Exp. The action of heat softens the iron, or steel, and diminishes the force, by which the spiral channels, made in the arrangement of the superficial atoms of the metal, retain their positions, and in part destroys that arrangement.

Ph. 138. The attractive force of a magnet is increased by placing a piece of soft iron opposite to either of its poles at a small distance.

Exp. The iron becomes a magnet as before explained, hence the gyrations of the ethereal matter about the magnet become more free, by finding a more facile entrance or exit, and hence its force is necessarily increased.

Ph. 139. Place a good bar magnet so that one of its poles may extend a little beyond the support, present a short bit of small iron wire, and it will be suspended at the pole by the attractive force, to the opposite end of this wire another small piece may be appended, and to this another, and so on, till a chain of small wires is formed, to the amout of ten, or a dozen, or more, according to the strength of the magnet, and the weight of the pieces of wire. Instead of the wire, little iron balls may be used.

Exp. The first wire becomes a magnet, as already explained, hence the next is attached to it, which then also itself becomes a magnet, and attracts the third, and thus

the process continues, till the power is insufficient to support another piece because of the weight.

Ph. 140. Things being as in the last, if a large piece of soft iron be placed a little below the last of the wires or balls, which are attached to the pole of the magnet, one or more additional bits of wire may be presented to the others, and will be attracted and supported.

Exp. The iron placed below the pole becomes a magnet by its proximity to the pole under which it is placed, and therefore its tendency will be to increase the current of ethereal matter through the magnet, and the series of wires or balls, which fully accounts for the effect.

Ph. 141. Instead of the large piece of iron, let there be placed under the chain of wires, the pole of another magnet, of the contrary name to that by which the wires are supported, then several others may be attached in succession.

Exp. This is accounted for as the last, by the increased current, but here the effect is greater, because of the permanent magnetism, and greater force of the magnet, which is substituted for the iron.

Ph. 142. When an additional number of pieces of wire have been attached by means of a large piece of iron, (*ph.* 140), or of the opposite pole of another magnet, (*ph.* 141), when the iron or magnet is carefully removed all or several of the additional wires will continue to adhere together, although they could not be attached at first of themselves.

Exp. While the iron, or magnet remained under the chain of wires, the current of ethereal matter was established through it, in consequence of which they become stronger magnets and consequently remain connected.

Ph. 143. When a chain of small pieces of wire has been attached to the pole of a magnet, as in *ph.* 139, 140,

or 141, consisting of as many pieces as it can support; then if the pole of another magnet of the same name, be gently moved towards the lower piece of wire, it will drop off, when the magnet is brought to some certain distance, then being moved a little nearer the next will fall, and thus in succession one by one, till most of them are removed.

Exp. Since a pole of the same name is presented, the ethereal currents oppose each other, hence the force by which the wires are appended is weakened, and at a certain distance the magnetism of the lowest wire is destroyed, and hence it falls off, and so of the rest, which shews the reason of these facts.

Ph. 144. The chain of wires appended as in the preceding phenomena, hangs perpendicularly to the horizon; but when the pole of another magnet is presented, the chain is inflected towards it, if it be a pole of the contrary name, and from it, if it be a pole of the same name.

Exp. The lower ends of all the wires are poles of the same name as that to which the upper wire is attached, and hence the effect arises from the attraction, which always takes place between contrary poles, and the repulsion between like poles.

Ph. 145. If a piece of pasteboard or other thin plate, not iron, be placed on a good bar magnet, and on this there be sifted some iron filings, the filings will arrange themselves, so as to form a multitude of curves, extending from the parts near one pole to those near the other, opposite to the poles, the lines will be straight and perpendicular to the direction of the magnet; and at the two ends curves will be extended from the poles towards the opposite parts, as may be understood by the dotted lines in *fig.* 85. It will be proper to shake the table or the pasteboard gently, in order to give freedom of motion to the filings, that they may take their proper positions.

Exp. Each particle of the filings becomes a magnet, as above shewn, and will therefore take the arrangement stated (by *ph*. 125 and 127), it is evident that the positions will be such as to form these curves : the little arrows in *fig*. 85, will give an idea of the form and directions of the curve lines produced in the filings.

Ph. 146. If two bar magnets be placed at a short distance in the same line with their contrary poles towards one another, and there be placed over them a piece of pasteboard with iron filings strewed over it, and if the table be struck gently several times, so as to shake the filings a little, they will arrange themselves in curves between the poles of the two magnets, as, in *ph*. 145, they did between the contrary poles of the same magnet.

Exp. The filings become magnetic, and the arrangement ensues precisely as above explained.

Ph. 147. The action of a large magnet extends to a greater distance than that of a smaller one, even in the case when the power of the smaller one is equally great at a very small distance.—*Musschenbroek* Diss. de Mag. Expt. 42.

Exp. The circumvolutions in the large magnet, though not of greater force, are of greater extent on the surface of the iron, and therefore extend to a greater distance in the air.

Ph. 148. If a magnet be suspended freely, it will turn one of its poles towards another magnet presented, and this directive power is apparent at distances, where the attraction between them is not perceptible.

Exp. The directive power will be rendered very evident on a freely suspended needle, by a very feeble current of ethereal matter, and hence the current produced in the air by the magnet at a great distance, though insufficient

to exhibit the effects of attraction, will readily influence the direction of the needle.

Ph. 149. If equal magnets be laid on each other, with the contrary poles together, their attractive virtue disappears, while in this state.

Exp. Here the current in the one passes to the other, and thus circulates through them, and hence the effect on neighbouring masses of iron must cease.

Ph. 150. If the magnets be suffered to remain together as in the last phenomenon, they will preserve, and sometimes increase, each other's virtue.

Exp. This arises from the same cause as stated in the preceding phenomenon, the current circulating through them, tends to preserve the channelled course, and if not already in its maximum state, will penetrate deeper, and improve the magnets.

Ph. 151. If the magnets be suffered to remain with like poles in contact they will destroy or injure each other's power.

Exp. Because in this case the currents meet between the magnets, and destroy that arrangement of their atoms, which is necessary to give and support their magnetism.

Ph. 152. The magnetic virtue is destroyed by a strong heat, especially if the magnet be suffered to cool not in the magnetic meridian.

Exp. The magnetic arrangement is destroyed by the heat, and is not re-produced in cooling, unless the body be in the magnetic line.

Ph. 153. Several magnets put together with like poles in contact, have a greater power than one of them, but much less than the sum of all.

Exp. In this case the magnets act in concert, because their currents tend to coalesce at their entering and leaving

the magnets; but the power falls short of the sum of their separate effects, because a portion of the effect is destroyed by the meeting of the currents between the magnets; and by the last phenomenon the magnetism would be injured by their remaining long in this position.

Ph. 154. The attractive power of a magnet may be increased, in many cases considerably, by connecting its poles by soft iron, suspending a weight, and gradually increasing the weight at proper intervals.

Exp. When a weight, as much as the magnet can support, is appended, the atoms of iron, which compose the magnet, are in some small degree drawn apart, or at least their cohesion is diminished near the surface by the weight, hence the ethereal matter circulating among them, as before explained, will more freely penetrate, and pervade the surface of the magnet, and strike deeper, so that it becomes capable of bearing a greater weight, when the additional weight is applied, the above cause is renewed, and a similar effect produced, and thus by repeated additions of weights, the magnet acquires an increased power.

Ph. 155. If two equally strong bar magnets be placed, the one on the other, with their like poles in contact, and if they have smooth surfaces, such that the upper can move with little friction on the lower, it will revolve, making half a revolution, so as to bring the contrary poles into contact.

Exp. The like poles repel each other, (*ph.* 118), the currents between them flow in contrary directions, hence the poles will separate by repulsion till they are at right angles to each other, the motion they have received carries them beyond this position, and they are then attracted (*ph.* 117), till the contrary poles are brought into contact; or rather repulsion continues in the angles

which first separate, and attraction is exercised in their vertical angles. (See Electro-Magnetism, *sect.* x).

Ph. 156. The force of the magnetic attractions, vary inversely as the square of the distance, according to the accurate experiments of M. *Coulomb*, yet other experimenters have concluded that the law of the force is different.

Exp. It follows from the explanations which have been given, that the ethereal matter revolving about a magnet will be more dense and rapid near its surface, diminishing gradually to considerable distances in the air, and, estimating from the point of greatest action, it is likely that the force of the fluid will diminish on a given line in the ratio of the distance of that line, and consequently on a given surface as the square of that surface, which will constitute the law of diminution above mentioned, but several circumstances, relating to the shape of the magnet, and the perfection of its magnetism, will tend to produce discrepancies.

Ph. 157. If a long bar or rod of soft iron be placed in the magnetic axis, that is, in the direction of the dipping needle, and if a magnetic needle, freely suspended, be made to descend either on the eastern or western side, so that its center be opposite the axis of the bar: while it is nearest the upper part, the north end of the needle will be deflected towards the bar, near the lower part the south end will be turned towards it, but at some intermediate point the needle keeps its natural position.

Exp. The bar is a magnet so long as it remains in this position, its upper end being a south pole, and the lower a north pole, (*ph.* 47), hence the upper part attracts the north end of the needle, and repels the south end, and the contrary at the lower end of the bar; and the power being sufficient only to deflect the needle a little from its

natural position, the north pole will be inclined towards the bar at its upper part, and the south pole at its lower end, but at some part between it will be equally attracted and repelled at both poles, and will consequently there keep its natural position.

Ph. 158. If instead of the bar of iron, a strong magnet be substituted, and placed in the magnetic axis with its south pole uppermost, and the needle be made to descend, as before, either on the eastern or western side, then (1) if the needle be not very far from the magnet, its north pole will be turned directly towards it, at the top; as it descends its north pole will point upward, it will turn as it approaches the bottom, where the south pole will point to the magnet, the needle having made a revolution on an axis passing through its center. The reverse will happen if it be carried upward. (2) But if the needle be carried down at such a distance that at the top or bottom a moderate deflection only is produced, then its north pole will incline towards the bar at the upper part, and the south pole at the lower, but opposite the center it will retain its natural position.

Exp. The 1st part is conformable to *ph.* 125, and the 2nd to *ph.* 157; various circumstances may produce slight differences.

Ph. 159. Let C, *fig.* 86, represent the center of an iron ball, SN a diameter parallel to the natural magnetic axis, EAWB a plane passing through the center C perpendicular to the axis SN, to which the plane *eawb* is parallel, ANBS a plane passing through the magnetic north and south poles of the horizon *n* and *s*, SENW a plane at right angles to it passing through the magnetic east and west points E and W: conceive all these planes to be extended beyond the ball, and it is found, that when the center of a good small magnet is any where in the plane

ANBS, or in that of EAWB, its declination is not affected by the iron ball, but when the center of the needle is in any other situation within the magnetic influence, its declination is altered, the north end being carried from the ball when the center of the needle is above the plane EAWB, and towards it when below that plane.

Exp. If a rod of iron were placed in the position SN, it would become a magnet, (*ph.* 41 and 47), the ethereal matter descending from S to N in a spiral course through its surface, a single spiral nearly coinciding with a plane perpendicular to SN; the same must evidently take place when the iron is spherical, the ethereal matter revolving (as shewn in *ph.* 41, 47 and 117) round the surface to a small depth in a spiral, from east by south to west, the spirals nearly coinciding with the planes *eawb*, EAWB at the parts where they are situated, in the same manner as the lines denoting the sun's declination nearly agree with the parallels to the equator, and like those will run nearer together where the power is most condensed, as at some distance from S and N, the extremities of the magnetic axis. The direction of the motion is denoted by the arrow heads. Hence when the center of the needle is in the plane ANBS, evidently it is equally affected by the hemispheres of the iron, by forces tending to keep it in that plane. Again when its center is in the plane EAWB, its north end is attracted, and its south end repelled by the upper hemisphere; also on the other hand its north end is equally repelled and its south end attracted by the lower hemisphere (see *ph.* 117, 118, 125, 157 and 158): hence its declination will not be affected while its center is in this plane. Next let the center of the needle be above the plane EAWB, then its north end is attracted, and its south end repelled by the upper hemisphere, more than the south end is attracted

and the north end repelled by the lower hemisphere, and therefore the north end will approach the ball, while the other recedes: the opposite effect, for similar reasons, takes place when the center of the needle is below the plane EAWB.

Note.—Mr. *Barlow* exhibited, and established the facts in this phenomenon by a series of accurate and well conducted experiments, in which he also shewed, that if EAWB be called the equator of the ball, and the distance in a great circle of a point on its surface from that equator be called the latitude of that point, the longitude of the same point being the distance on the equator from E to a secondary circle passing through it, we shall find, the longitude being given, that the tangent of deviation of the needle varies, as the sine of twice the latitude, also when the latitude is given, the tangent of deviation varies nearly as the cos. of the longitude; hence when neither are given, the tangent of deviation varies as the rectangle of the sine of twice the latitude and cos. of the longitude.

The Declination of the Needle.

Ph. 160. The direction of the magnetic needle, duly suspended, is subject to continual fluctuations, but on the whole it advances annually, the same way in its changes, as the observations, during a period of many years, sufficiently prove. Thus at *London* and *Paris* it has been advancing westward since the time it was first noticed, which will be apparent from the numbers set down in the annexed table.

Year.	Decl. at London.			Year.	Decl. at Paris.		
1576	11°	15′		1580	11°	30′	
1612	6	10		1610	8	0	
1622	6	0	East.				East.
1634	4	5		1640	3	0	
1657	0	0		1664	0	40	
1665	1	22		1666	0	0	
1666	1	35					
1672	2	30		1670	1	30	
1683	4	30		1683	3	50	
1692	6	0		1692	5	50	
1700	8	0		1700	8	12	
1722	14	22		1722	13	0	
1740	17	0		1728	14	0	
1750	17	48		1762	18	15	
1770	21	9		1771	19	45	
1780	23	17		1792	22	0	
1800	24	3		1800	22	0	
1820	24	34		1802	22	0	

These numbers to the year 1700 were selected from *Musschenbroek's* Dissertations on the Magnet, the rest of the table for *London* from Mr. *Barlow's* Essay, and those for *Paris* from *Enfield*, for 1728 and 1771, and the three last are from a paper by M. *La Lande*.

Exp. It was shewn in *ph.* 10, 13, 18, 41, and 42, that ethereal matter is raised at the tropical regions, and conveyed towards the north and south spirally westward, more and more entering the earth as we approach the higher latitudes, till it is so far condensed, and also resisted by the dry and cold air, and frozen particles of vapour, near the poles, where the vapours are generally in a frozen state, that it enters very copiously in an irregular zone at some distance from the pole, perhaps 15° or 20°, and that in this zone it finds a passage to the earth more easily in some part or parts than in others, and that in consequence of changes in these circumstances, and other atmospheric phenomena, the direction of the ethereal current is considerably affected. Again in *ph.* 41 and 42,

and in some others, it is shewn that the magnetic needle is formed by the action of this current, which under proper circumstances produces round it a spiral path, the channels of which are nearly at right angles to its length, especially near its poles, and that therefore the needle will place itself nearly at right angles to the direction of the current. Now from all this it will be very evident that great fluctuations ought to take place in the direction of the needle, for the action of heat, the process of evaporation, and condensation of vapour, and the electrical state of the air, with other atmospherical changes, will greatly affect the ethereal current, and cause its direction to vary much, according to the nature and differences of the actions of these causes. But, since the motion of the ethereal current is always from the east, westward, the place or part of the abovementioned zone, where the fluid enters the earth most copiously, will be urged continually forward according to that direction, since the current presses always on towards the western side of it, and this part of the zone being the magnetic pole, it follows that this pole will continually advance, and the same will apply to any other magnetic pole or poles, which may be in this zone; the like will also happen to the south magnetic poles of the earth. It is not however necessary that these poles in the Antarctic regions should move with the same velocity as those in the north. From the above deductions it will clearly follow, that the needle at a given place will for many years together alter its declination towards the same part. Also if there be more than one magnetic pole in the same zone, it will be right to admit, that the motion of the one will be regulated, in some degree, by that of the other.

Ph. 161. The declination of the needle is different in different places, being in some places more or less west-

erly, in others easterly; and again, in several places the needle points due north and south.

Exp. A very little attention to the preceding explanation will render the reason and cause of this fact very evident; since we hence clearly perceive, that the current must have different directions round the pole, in respect to most different places, and the same direction in relation to certain other places.

Ph. 162. The motion of the magnetic pole is not uniform, but in some years it advances more than in others; or in some periods of time of a given length, its motion is greater than in other equal periods. This will be evident from consulting the table either for *London*, or that for *Paris*, in *ph.* 160, particularly the latter; thus, from 1720 to 1725 the needle was stationary at *Paris*, as stated in *Musschenbroek's* table, being 13°, so likewise, in 1716 and 1717, it remained at 12° 20′, and in 1718 and 1719 at 12° 30′; but in other years the change was more or less; thus from 1700 to 1701, it increased 13′, and in the next year its progress was 23′. Were we to compare the advance of the needle in periods of five years, or ten years, &c. we should still find it quite irregular. Inequalities more or less will be found at most places where good observations have been made.

Exp. It has been shewn in *ph.* 160, that the place or part of the irregular zone noticed in *ph.* 18, 41, &c., at which the ethereal matter most copiously enters the surface of the earth, is urged westward, because the motion of the current is in that direction; now, on account of the different nature of the surface of the earth in the several parts of this zone, it is to be expected that a much greater resistance will be opposed, to the advance of the space which determines the pole, in some parts than in others, and hence its irregular motion is the necessary

consequence, which irregularity will also be promoted by changes in the weather, and differences in the seasons.

PH. 163. In some years during the period in which the magnetic declination in general is advancing westward, on account of the progress of the pole, it has been found to be, in certain places, somewhat retrograde in its motion, thus, at *Paris* the declination was 3′ less in 1713 than in 1712, and 20′ more in 1714 than in 1715, and the like has happened in other years. *Musschenbroek*, Diss. de Mag. p. 153.

Exp. This singular fact may be accounted for from the great difference in the weather in different years, thus when extremely cold weather for a long time prevails near the north pole, the irregular zone, already described, will recede farther from the pole; and when cold dry north-west winds are long continued, they will evidently tend to oppose the ethereal current, and consequently retard the progress of the magnetie pole, and these causes with other atmospherical phenomena are quite adequate on some occasions not only to check and arrest the progress of the magnetic pole, but even to cause it to return in some small degree, especially at such places as are so situated in respect of the pole, that the parts of the earth then in the magnetic meridian of that place may contribute to promote this effect.

PH. 164. The progress of the pole is not the same at equal declinations on the east and west of the same place; thus at *Paris* in 1666 the declination was 0; 56 years prior to that time, *viz.* in 1610, it was 8° east; but 56 years after it was 13° west.

Exp. The preceding explanations equally account for this anomaly as for those already noticed.

PH. 165. The motion of the magnetic pole is not the same at the same time, if estimated from two different

places, even when those places are not very remote. Thus when the pole appeared stationary at *Paris*, or even retrograde, its motion was progressive at *London*, and by the table in *ph.* 160, it appears that the declination was considerably more to the west at *London* than at *Paris*, till about 1700, when it was nearly the same at both places, after which it became again much more westward at *London* than at *Paris*.

Exp. The place of the pole, as indicated by the position of the needle, will not always be in the plane passing through the needle, and the place where the ethereal matter most copiously enters the earth, which may be called a general magnetic pole of the earth, because although the direction of the ethereal current, and consequently the position of the needle, will be greatly affected by the situation of that pole, it is not altogether determined by it; since it must be evident, that the nature of the parts of the earth, lying between the place and the general pole, will greatly affect the direction of the current at the place, particularly if its adjacent parts in that plane contain ferruginous minerals, and this is one grand cause of the irregularity of the pole mentioned in *ph.* 163, as observed from a given place.

PH. 166. Mr. *Barlow*, calculating from accurate observations, finds "that every place appears to have its proper poles; and the only limits we are able to assign to their situations, is, that as far as observations have yet been carried, they appear to fall somewhere within the two frigid zones, but varying through all possible degrees of longitude and latitude within these limits."

Exp. This is in exact accordance with the foregoing exlanations, and the more remarkably so, if we allow as is most probable, that there are at least two general poles, in each irregular zone, (noticed in *ph.* 18 and 41, and

some others), encircling the terrestrial poles at some distance.

Ph. 167. The declination of the needle is also subject at a given place to a diurnal variation; in these parts of the earth it usually increases westward in the forenoon, and decreases in the afternoon; but these motions are generally modified, so that in the morning the needle first approaches a little towards the east, and then follows its usual motion westward; thirdly its motion eastward in the afternoon follows; but fourthly, this is succeeded in the evening by a small motion towards the west. *Haüy's* Nat. Phil. vol. ii. p. 110.

Exp. This is a natural effect of the different electrical states of the atmosphere, as explained in *ph.* 11. Thus at sun-rise the positive electrical state of the air increases; and from the reason of this shewn in the explanation of *ph.* 11, it appears that the electric fluid will tend in the morning to enter the earth more eastward toward the parts first warmed by the rising sun, so that the general current of ethereal matter will be deflected somewhat from its course, and the general magnetic pole itself will tend a little eastward; hence the needle must, when other causes do not intervene, first, in the morning, move a short time easterly. Again, as appears by *ph.* 11, the positive electrical state of the atmosphere decreases till about the middle of the day; hence, for the reverse reasons to those just mentioned, the needle must advance westward. In the afternoon the positive electricity increases again, and hence, the needle returns once more towards the east; in the evening also the electricity decreases, and the needle of course advances to the west.

Ph. 168. The general diurnal motions of the needle, as just described, are subject to various changes, the quantities and maxima of the motions both ways being very

different on different days; and the needle is subject to frequent oscillations.

Exp. The changes in the atmosphere continually arising from heat, cold, moisture, or wind, &c. are quite sufficient to account for these variations, according to the views which have been presented.

Ph. 169. The deflections of the needle are also considerably affected by the season of the year. Thus January exhibits a small variation, March a high one, February and May nearly agree in the quantity of variation.

Exp. The different degrees of heat and cold, moisture and dryness, and other circumstances, combined with the position of the sun to the northern hemisphere of the earth, will produce these changes, as a consideration of *ph.* 167 will evince.

Ph. 170. Magnetic needles will sometimes vibrate 7′ or even 14′ without any apparent cause.

Exp. Changes to this, or even to a greater amount may easily be conceived to arise from changes in the upper parts of the atmosphere, which are not easily noticed by an observer.

Ph. 171. A south-west wind seems to increase the variation and the unsteadiness of the needle.

Exp. This wind is generally moist, and hence will more rapidly transmit electric fluid to the earth, and hence will deflect the current in northern regions towards that quarter from which it blows, and this necessarily increases the western variation, since the needle is nearly at right angles to the current at any place, and as the direction of the current varies so must that of the needle.

Ph. 172. The declination of the needle at the same place and time is generally a little different, as observed by two different needles.

Exp. It has been several times stated, that the direction which the needle takes is nearly at right angles to the ethereal current at the place where it is suspended; a perpendicular to the current would be exactly its position, if the channels formed round the magnet, when it receives its magnetism, as in *ph.* 41, and some others, were at right angles to the axis of the magnet; but this cannot be the case exactly, since the ethereal matter passes round the magnet in spirals from one end, where it enters, towards the other where it goes off; hence the position of the spirals to the axis of the needle will determine the position which it will take in respect of the current; now from the difference in the iron or steel, in two needles, or their different degrees of hardness, or temper, it cannot be supposed, that the positions of the spirals, in respect to the axis, will be always the same exactly in both needles, with whatever care they may have been magnetised; hence the two needles will shew some small difference in their position. Again, the magnetism is much more permanent and fixed in some needles than in others; and hence when the direction of the ethereal current undergoes its diurnal variations, (*ph.* 167), the position of the spirals in the less permanent magnetic needle will suffer some variation; hence a new kind of unsteadiness is produced in that needle, while the more perfect one is steady to its position; in respect of the current however, it may vary. Thirdly, It is extremely difficult to give uniform magnetism to needles; and, if a needle have a consequent point, although in a small degree only, the diurnal changes in the ethereal current will affect it differently on that account; hence it can rarely happen that two needles will take the same direction, or that they will vary in the same ratio during the day.

Obs. From this difference it has been concluded, " that

when needles of different shapes, or more than one is used, though they may be similarly, are not proportionably, affected by all local and electrical influences, and especially those possessing magnetical properties, as might be anticipated." It is hence concluded, " that when observations are made for scientific applications with different needles, it is essential that they should be made of similar materials, and possess—(1) A similar magnetic power at any given place. (2) That they should be of the same shape, in order to have that power similarly disposed. (3) That they should be of the same size, weight, and temperament, in order to retain their virtue; and (4) That the box, stand, and other parts of the apparatus should be similar, that all influences might act equally upon them." Such conclusions will naturally result also from the preceding phenomena; but still it will be very difficult to obviate all the causes of difference.

Ph. 173. The needle is frequently agitated during tempestuous weather, and the eruptions of volcanoes.

Exp. These changes of the weather, and concussions of the earth, will, of nesessary consequence, according to what has been advanced, affect the course of the ethereal current in many places, and thus vary the position of the needle.

Ph. 174. Brilliant and active coruscations of the Aurora Borealis cause a deflection of the needle, almost invariably, if they appear through a hazy atmosphere, and exhibit the prismatic colours.

Exp. The account given of the Aurora Borealis in *ph.* 12, 13, &c. will at once shew the reason of this effect, the cause of this meteor and of magnetism are closely connected.

Ph. 175. " Distant polar lights, even if they are not seen in a given place, exercise an evident influence on the

direction of the magnetic needle there." *Arago and Others*, Phil. Mag. vol. ii. p. 334.

Exp. This is in accordance with the preceding phenomenon, and since the Aurora is active in elevated parts of the atmosphere, its influence must extend to great distances.

Ph. 176. Various natural causes act upon the magnetic needle, so as to cause a sudden change in its position, or at least to disturb the regularity of its diurnal variations, and of all these causes the Aurora Borealis appears to be the most energetic and infallible. Edin. Phil. Journ. for Sept. 1828.

Exp. The two last, and *ph.* 170, will account for the effects here stated.

Ph. 177. The declination of the needle is considerably affected by heat.

Exp. In consequence of an increased temperature, the ethereal current will enter the earth in the polar regions, especially at the general magnetic poles, in a space more extended in length and breadth, and will be more diffused, and hence the needle must be subject from this cause to an alteration in its position.

Ph. 178. Many iron mines are found to be magnetic, and they generally contain natural magnets.

Exp. Since iron long remaining in the same position acquires permanent magnetism, it follows that the iron in mines is susceptible of acquiring the same properties.

Ph. 179. The magnetic needle in mountainous districts is subject to extraordinary motions, and great aberrations on being moved to small distances, and to different parts of the same mountain.

Exp. Many mountains contain much iron, and this is in general magnetic, and hence it affects the needle by

its attractions and repulsions, which have been already explained.

PH. 180. There are found, by observations, certain lines on the earth where the needle has no declination, that is, in which its direction is north and south. These lines are in many parts very oblique to the geographical meridians, they contain many inflections, and constitute very irregular curves, which are continually undergoing variations in place and form. These curves are rather to be considered as irregular zones than as single lines.

Exp. The different general magnetic poles in the frigid zones and their continual but unequal oscillations, and, upon the whole, their progress westward, will not only shew that there ought to be some such lines where the compass has no declination, but also that these lines should be very changeable in form and position.

PH. 181. In Dr. *Halley's* chart, as laid down for 1700 by *Musschenbroek* in his Dissertation on the Magnet, one of the lines of no declination coming from the southern regions of the Atlantic ocean crosses the meridian of *London* in 58° S., and extending northward, a little inclining to the west, passes somewhat east of *Ascension* island, and crosses the equator at about 15° W. long. and rising northward it more rapidly inclines towards the west, till passing through the *Bermudas*, it proceeds nearly west to *Carolina* in the *United States.* Observations made in several succeeding years shewed that the northern part of this line moved westward, and the southern part eastward.

Exp. The westward motion of the nearest general magnetic pole of the earth in the north frigid zone will account for the westward motion of the northern part of this line. Also if we allow that there are two principal magnetic poles in the southern frigid zone, which, from

what we have advanced on this subject, is rendered almost certain, then if one of these poles was at that time in a little more than 90° west longitude, and the other in less than 90° east longitude, the motion eastward of the southern branch would be the natural consequence. But if there be one general pole in the south frigid zone, its position evidently might at that period be such as to produce the observed effect.

PH. 182. In the same chart we find another line marked in which the needle has no declination; it passes through *New Holland*, the islands of *Timor*, *Celebes*, *Mindora*, and the eastern part of *China*, cutting the equator in long. 119° E.

Exp. If we admit of a general magnetic pole within the antarctic circle, somewhere between 50° and 70° of east longitude, as stated in the last to be probable, this line ought to be found in or near the regions where it is delineated. However the nature of the surface of the earth, as consisting of land, water, and mountainous districts, &c. ought to have a considerable effect, as well as the general magnetic poles, in regulating the positions, and motions of the lines of no declination, which is the case in fact.

PH. 183. At present the line of no declination is returned nearly to the situation it had in 1700, at its southern part in about 60° south latitude, where it cuts the meridian of *London*, but from thence it now proceeds, north-west to the coast of *Paraguay*, where it takes its direction nearly in the meridian along the coasts of *Brazil*, till reaching the latitude of *Cayenne*, it turns suddenly to the north-west, where it is directed to the *United States*, and other parts of *North America*. The general motion of this line is therefore westward, but the motions of its different parts are unequal, and sometimes in op-

posite directions, and doubtless its motions are subject to very great variations and irregularities.

Exp. All this is exactly conformable to, and in accordance with, what we have already advanced on this subject.

Obs. There are found at present three, or four lines of no declination, the phenomena of which answer to the explanations given of the corresponding appearances, and it will be unnecessary to swell this work with an account of these, since the way has been opened sufficiently for pursuing such researches.

Ph. 184. The lines, in which there is any particular declination of the needle east or west, are also irregular curves, their general motions, and those of their different parts are also very irregular, and are farther modified by the positions and variations of the lines of no declination.

Exp. These facts necessarily follow from the reasons assigned, in the four last phenomena, respecting the line where there is no declination.

Inclination of the Needle.

Ph. 185. The magnetic needle is also subject to another kind of deviation. Let it be placed in equilibrium on its pivot, before it is rendered magnetic, then, after it is magnetised, it will be found, that, at most places of the earth, its equilibrium will be destroyed, the north pole being depressed on the north side of the magnetic equator, and the south pole on the south side. This is called the dip, or inclination of the needle.

Exp. Suppose AB, *fig.* 81, a north magnet, of which

A is the south, and B the north pole, and which had been previously balanced on an axis passing through its center of gravity; when magnetised, and placed in the plane of the magnetic meridian, let a person, on the east side, look westward on this needle with the end B northward, and it will be seen, and understood from *ph.* 41, and others, that the ethereal matter, revolving round the magnet, proceeds downward on the side facing him, and towards the end B; also the ethereal current, which is going round the earth, is moving downward and towards the west, hence the combined effect will be an action on the east side of the needle on those faces of the spiral channels in the magnet, which are towards B, and this will cause a depression of the end B, more or less as the terrestrial current is more or less directed downward. Next, let a south magnet, AB, *fig.* 82, be similarly circumstanced with the end A northward, this end being in this needle its north pole. Here it will be seen, that the ethereal current still descends on the side facing the spectator, but now it proceeds southward, *viz.* from A towards B, and the terrestrial current as before flows northward, still descending, hence it now falls on the south sides of the spiral channels in AB, that is, on the side nearest B; but these spirals likewise proceed the opposite way to those in *fig.* 81, hence evidently here, as well as in the north needle, the combined effect of the two currents is to deflect the north end downward. The explanation would be similar when the needle is in southern latitudes.

PH. 186. In the tropical regions a course of points is found, in which the needle has no inclination, that is, in which it always rests horizontally; if these points be connected, so as to form a curve round the globe, this line is called the magnetic equator, or rather, the magnetic equator is an irregular belt round the earth, extending

more or less on each side of the terrestrial equator, but no where exceeding the distance of twelve degrees from that circle.

Exp. To these tropical regions we have shewn there is a continual influx of ethereal matter, such as caloric and the electric fluid, and that this, being elevated, is necessarily carried northward and southward, descending as it reaches high latitudes. Hence, in or near the equator such spaces ought to be found in all longitudes: but the different distribution of land and water, and particularly the position of the general magnetic poles, will prevent the coincidence of these points with the equator, except at certain intersections, hence we have an adequate solution of these facts.

Ph. 187. It has been ascertained by M. *Biot*, from a selection of good observations made by navigators, that the magnetic equator intersects the terrestrial equator in about 113° of west longitude, proceeding east southward, in an angle of about 12°, and forming nearly half of a great circle of the earth, so that it again intersects the equator in long. 67° E., or nearly so: but instead of pursuing its course far on the north side of the equator, it is again found in the southern hemisphere nearly in long. 156° W. and latitude 3° 13′ S. instead of 8° 36′ N.

Again the magnetic equator was observed in the *Chinese* sea, in long. 166° E. and lat. 7° N. hence, it is concluded that there are at least three, and very probably there are four intersections of the magnetic and terrestrial equators. It may be here added, that if we were furnished with a sufficient number of good observations, it would very likely be found, that the course of the magnetic equator is very irregular, and that several longitudes will give a place on each side of the equator on the same meridian, where the needle has no inclination, and that at some of

these places it varies considerably at different seasons of the year.

Exp. The effects of the burning sands of northern *Africa,* and of the lands in southern *Asia,* the difference of the degrees of heat, which the atmosphere receives over dry land and over water, with the difference of the electrical conducting power of land and water, will be sufficient to cause innumerable inflections in the magnetic equator, and much more in some places than in others. But to ascertain these points accurately, many more good observations than those we now have are requisite.

Ph. 188. The inclination of the needle continually increases, as we recede on either side from the magnetic equator towards the north or south.

Exp. The ethereal terrestrial current, as frequently before shewn, falls more directly towards the earth as we advance towards the magnetic poles, and hence according to *ph.* 185, the effect is produced.

Ph. 189. The inclination, as well as the declination of the needle, is subject to continual variations, and to anomalous movements.

Exp. This is a necessary consequence of the changes in the declination, and arises from like causes.

Intensity of the Needle.

Ph. 190. The intensity of a magnetic needle, or the force by which it tends to return, when moved out of its natural position, which is measured by the number of oscillations performed in a given time, is least at the mag-

netic equator, and continally increases as we approach the magnetic poles, these facts have been clearly and satisfactorily shewn from the observations and experiments of *M. de Humboldt.*

Exp. From what has been advanced respecting the ethereal current about the earth, it is evident, that it is more diffused and expanded in the equatorial regions, than in other parts, and more contracted and dense as we advance towards the magnetic poles; hence evidently the intensity of the needle ought to be least at the magnetic equator, and greater as we advance towards the poles.

PH. 191. The intensity of the needle is also greatly affected by local causes; thus M. *Biot* found that the needle vibrates much more rapidly on the *Alps* than at *Paris.*

Exp. The presence of ferruginous matter in the mountains has been shewn to affect the position of the needle, and it will, as well as any other magnetic body, increase the quantity and density of the ethereal current about the magnet, and consequently will augment its intensity.

Action on different Bodies.

PH. 192. Besides iron and steel, it is found that nickel and cobalt are susceptible of acquiring, and retaining the magnetic virtue, and of forming energetic magnets.

Exp. For this purpose it is only necessary that the forces, the extent of the spherules, and the arrangement of the atoms, which compose these bodies, be such as will admit the terrestrial ethereal current to pass along them, without penetrating the surface to a great depth, or to a

great length in the same direction, and also so, that having been brought by the current into a particular arrangement, as explained respecting iron in *ph.* 41, they may retain that arrangement; and that nickel and cobalt, at least when of some certain degrees of purity, are so, experiment shews.

PH. 193. No other bodies except iron, nickel, and cobalt, are as yet found capable of possessing magnetism in any considerable degree.

Exp. If the atoms of bodies, and their arrangements be such, that the ethereal current cannot penetrate their surfaces at all, or such that it can pervade their whole substance; or again, such, that they are not susceptible of taking or retaining the proper arrangement in spiral channels by the actions of the ethereal current, they cannot be rendered magnetical: now it seems reasonable to conclude, that some of these conditions will apply to most bodies, hence very few bodies will be capable of energetic magnetism.

PH. 194. Yet most bodies seem to be capable of possessing a very slight degree of magnetism; thus, if two strong magnets be placed in a line with their opposite poles to each other, and distant about 25 millimetres, (nearly one inch), and a small cylinder about 8 millimetres (nearly one-third of an inch) long, of any material substance, be suspended freely between them, on a fine silk thread, such as it comes from the silk worm; the suspended cylinder takes exactly the direction of the magnets, and if put out of this line, it invariably returns into it, after a certain number of oscillations. This was first shewn by M. *Coulomb*, who performed the experiment with cylinders of gold, silver, copper, glass, chalk, bones, and different kinds of wood, all of which felt the action of the magnetic bars.

Exp. It is probable that these bodies possess a slight degree of magnetism, although not very energetic, as observed in the last explanation, but if not, still such light bodies, thus suspended, should be expected thus to be reduced to the direction of the magnetic spiral vortex, in which they are involved. See the explanations of *ph.* 117, &c. respecting magnetic attractions, and repulsions.

Ph. 195. The forces, by which the several bodies above mentioned, return to their first situation, when made to oscillate, are very different for the different bodies.

Exp. This favours the idea, that these bodies are really magnetical, and their different degrees of susceptibility to receive magnetism, accounts for the fact. But the same may be accounted for by the differences in the structure of their superficies.

Ph. 196. A very small portion of antimony, combined with iron, prevents it from acquiring the magnetic properties.

Exp. This may, and doubtless does arise, from the new arrangement in the particles, produced by the foreign body.

Ph. 197. The declination and inclination of the magnetic needle take place in the vacuum produced by an air-pump.

Exp. The ethereal current pervades the receiver in which the needle is placed, and produces its effects as in the air; and this action tends to confirm the proposition, that an ethereal current flows round the earth.

Ph. 198. Magnetism operates in elevated situations; thus, *Gay Lussac* and *Biot*, having ascended in a balloon, found that the magnet attracted iron, and the needle was affected by the earth's magnetism at an elevation of 4,000 metres, (about 2½ miles), above the earth's surface.

Exp. The current of ethereal matter, which has been shewn to revolve about the earth, descends in its progress as before described, from the highest parts of the atmosphere, and hence ought, at much greater elevations than the one given as an instance, to produce the effects of magnetism.

Ph. 199. Electrified magnets attract iron as when not electrified.

Exp. The diffusion of the electric fluid over the surface of the magnet does not destroy the arrangement of its superficial atoms, and hence does not destroy the magnetical effects.

Ph. 200. When the magnet is exposed to a continuous current of electric fluid, it is considerably influenced by its action, which changes the direction of the needle, which, when not restrained by other causes, is found to take a position nearly at right angles to its course.

Exp. This is in exact accordance with all the explanations we have given in reference to magnetism, and it may be observed, that all these explanations agree so remarkably, as greatly to corroborate each other, but the particular effects of the mutual actions of electricity and magnetism belong to the next section, in which the subject will be investigated.

SECTION X.

ELECTRO-MAGNETISM.

This branch of science, denominated Electro-magnetism, because it includes the consideration of many phenomena, in which electrical and magnetical effects are combined, will, with other noble achievements, remain a lasting monument of the industry, skill, and success of the philosophers, who grace the annals of modern times.

The honour of first exhibiting the leading facts, which belong to the class of phenomena comprehended under this designation, is due to M. *Oersted,* Professor of Natural Philosophy, and Secretary to the Royal Society of *Copenhagen,* who made the discovery of a marked and mutual action between the magnet and the wire which joins the extremities of the voltaic pile, when in action. The subject has been pursued, with laudable zeal, by the philosophers of *Britain,* and those of the *Continent.* Several

theories have already been proposed to account for the facts which experiment has developed, but we need none of them, and shall proceed to notice the principal phenomena, which have been well established.

The sixteen phenomena which are first explained, with the exception of the sixth, are taken from *Demonferrand's* Manual of Electro-dynamics, translated by Mr. *Cumming*. The term Electro-dynamics has been preferred by some, as an appellation to denote this branch of science.

Mutual Action of Condutcors.

PH. 1. If a slender copper wire, armed with steel points, and covered with silk, except at the steel points, and bent into the form *abcde*, *fig.* 95, have its two horizontal parallel branches, *ab*, *ed*, placed so as to float in two parallel channels of mercury, separated by a non-conductor, and the ends of the channels towards *a* and *e* be connected, the one with the positive, and the other with the negative end of a very powerful voltaic arrangement, the wire will move in the direction *ab*, *ed*, till it is stopped by the ends of the channels.—*Demonferrand's* Elect.-Dyn. by *Cumming*, sect. v. p 11.

Exp. This motion is produced by a cause similar to that by which the electrical fly moves; since there is a repulsion between the fluid leaving the mercury and entering the wire at one end, (*prop.* 14, *cor.* 9, *sect.* ii.), and the reverse at the other, both equally conspire to promote the same effect; hence, the wire moves as above stated. Steel points are most suitable for this purpose,

because the iron does not amalgamate with the mercury; hence there is not perfect contact, and the small spark passes as above noticed. The voltaic action must be powerful, and the wire small, otherwise the repulsion will not be sufficient to produce the motion of the wire in the mercury.

Ph. 2. If two wires, sufficiently near to each other, be connected with the extremities of a voltaic apparatus, so that the electric current may pass through them both, and towards the same parts, the wires will attract each other; and if one, or both, have great freedom of motion, they will approach and adhere together.

Exp. Let AB, CD, *fig.* 87, be the two wires, in which the electric currents are moving from A to B, and from C to D; that is, let A and C communicate with the positive, and B and D with the negative end of the battery. Now, since an electric current is flowing along AB, A being positive, and B negative, the air on every side of AB will be affected to some distance, (*prop.* 27, *sect.* ii.), and the atmospherules of the air around it will be extended towards the negative end, (see *ph.* 62, *sect.* vii.), and the current of ethereal matter, which is continually passing in the atmosphere, (*ph.* 10, *sect.* ix.), will be directed the same way to some distance, in the neighbourhood of the wire, on all its sides. The same applies to the wire CD. Hence, the atmospherules of the atoms of the air between the wires will be most of all extended in the direction of the motion, and the current will flow most freely on the sides of the wires which face each other; hence, the entire action will be such, that the two currents will tend to become one; and, since by this means the resistance is in part removed from the interior sides of the wires, while it remains on the opposite sides, they ought to approach, and hence arises the

attraction; and this will evidently hold, whether the wires be parallel or not, provided they are not far distant.

PH. 3. If the two wires meet at any angle, as ABC, or ABC′, *fig.* 88, and both the currents be moving toward the angular point B, or both from it, they will still attract each other; and if one, or both the wires have great freedom of motion, they will approach, and adhere, as in the case of parallel wires.

Exp. If both the currents flow towards B, they will come near enough to produce the effects stated in *ph.* 2, and hence the wires will approach, and the angle ABC, or ABC′, will be diminished, consequently, the effect will be increased, because of the greater proximity of the wires when meeting in a smaller angle, therefore the wires will continue to approach till they coincide. If the currents flow from B towards A and C, the same reason applies, for still the atmospherules of the atoms of the air are elongated the same way by both wires, and the general current of ethereal matter always in the air, is here directed in the same way by both, so that the attraction equally takes place: or, if the air be removed, the general body of ethereal matter present, even in the best vacuum we can produce, will similarly contribute to cause this attraction.

PH. 4. If the two wires, as in *ph.* 2, are so connected with the battery, that the current in the one moves in the opposite direction to that in the other; such as would arise by connecting A and D, *fig.* 87, with the positive, and B and C with the negative end of the battery; the wires will repel each other; that is, if one or both be free to move, they will recede to a certain distance.

Exp. Here the currents of ethereal matter, along and in the space between the wires, are in opposite directions, and therefore tend to put such other ethereal matter, as is in their vicinity, into these opposite directions; hence,

the currents in the interior, between the wires, impede each other, while on the opposite sides their course is uninterrupted; on this account the wires will recede till an equilibrium is attained, standing at some distance, greater or less, according to the quantity of the electric current, and the weight of the wires.

PH. 5. If the two wires meet, forming an angle, as at B, *fig.* 88, and the current flow towards the angular point B, in the one, and from it in the other, the wires will recede, if either of them have great freedom of motion.

Exp. The opposite currents must, according to the last explanation, produce a powerful effect near the angular point B, to separate the wires, which will cause in them a tendency to recede, as in *ph.* 4, and hence to turn on the point B, so as to form a larger angle.

PH. 6. The attractions and repulsions, mentioned above, take place in the vacuum of an air-pump.

Exp. The ethereal matter which revolves about the earth pervades this vacuum, and the conspiring electric currents, as in *ph.* 2 and 3, will tend to become one, involving the wires in its most dense part, and soliciting them toward each other, as in the common atmosphere. In like manner, when the currents are in the contrary directions, they will impede each other, as in *ph.* 4 and 5, and produce the recession, and apparent repulsion of the wires.

PH. 7. If the wires intersect each other extending both ways beyond the angular point, the attractions and repulsions are stronger than when they are not so extended.

Exp. Let the directions of the currents be according to the lines CP, and DQ, *fig.* 89, intersecting at *a*; then the attraction between C*a* and D*a* is increased, by that which takes place between *a*Q and *a*P (*ph.* 3), and this

is further increased by the repulsion, which arises between Ca and aQ, and that produced between Da and aP (*ph.* 5); hence the force by which Ca and Da approach, and Ca, and aQ recede, is augmented on all parts, and consequently the effect becomes much greater.

Ph. 8. "The repulsion, existing between two parallel currents, when passing in opposite directions, is changed into attraction, when they are in the same direction; and the attraction in this case is equal to the repulsion in the former."

Exp. The first part will be evident from *ph.* 2 and 4. Let one of the conductors as CD, *fig.* 87, be returned parallel to itself as in the dotted line *ef*, so that the current passing through CD is returned by *ef* very near it, and of the same length, then the tendency in CD to promote or impede the current between AB and CD, ought to be counteracted by the equal and opposite current *ef*, as it is in fact.

Ph. 9. The mutual actions between two conductors is reversed by reversing the current in either of them. But it will become the same by changing the direction of the current in both.

Exp. The explanations of the preceding phenomena will be sufficient to render the reason of this manifest.

Ph. 10. If the two wires CP, DQ, *fig.* 89, be at a small distance above each other, but not in contact, and free to move about their common perpendicular, passing through *a*, they will assume a parallel direction.

Exp. The reason of this fact is manifest from *ph.* 7, since there is a repulsion between two of the opposite angles, and an attraction between the two other angles.

Ph. 11. When the wires as in the last phenomenon are become parallel, their position will be that in which the currents move the same way in both.

Exp. The opposite angles in which the repulsion is, are those in which the currents are moving contrary ways (*ph.* 5), and those in which the attraction is, are those in which the currents are moving the same way, hence the wires must assume the position, in which the currents move through them in the same direction.

Ph. 12. If the electric current be conveyed through an extended fixed wire CD, *fig.* 89, and also through another wire *ab*, freely moveable about one end *a*, and its course be terminated at the other end *b*; the wire *ab* will move about *a*, so as to place the course of the electric currents in opposite directions, when the current in *ab* is flowing towards CD, and in the same direction, when its course is from CD towards the opposite parts.

Exp. Draw *nm* parallel to CD through *a*, and first let the current in CD move from C to D, and that in *ab* from *a* towards *e*, a point in CD. Now there will be attraction between C*e* and *ab* (*ph.* 3), because both the currents are moving towards *e*, and the effect of this attraction may be represented by a line drawn from *a* in the direction *a*C. There will also be a repulsion between *e*D, and *ab* (*ph.* 5), because the currents are moving one from *e* and the other towards it, and this repulsive force may be represented by some part of AQ, in the direction D*a*; hence the resultant, reduced to the parallel *nm*, will be in the direction from *a* towards *n*; therefore *ab* will be solicited towards *an*, where the currents in *ab* and CD will be in opposite directions. Next let the current in *ba* be from *b* to *a*, while that in CD is as before, then the repulsion is between C*e* and *ba* (*ph.* 5), and the attraction is between *ba* and *e*D (*ph.* 3); hence the resultant, reduced to the parallel *mn*, is in the direction *am*, in which the currents move towards the same parts. In the same manner it may be shewn, that if the wire *ab*, be on the

other side of the parallel *mn* as in the position *ab'*, it would move about *a* towards *am*, when the current is from *a* to *b*, and towards *n* when it is in the contrary direction.

PH. 13. Things being as in the last, the wire *ab* will revolve about the point *a*; and the current in CD being from C to D, the end *b*, while it is situated between the parallels CD, *mn*, will move in the direction of the current CD, from the parts C towards D, when the current in *ab* is from *b* to *a*, and the contrary when it is from *a* to *b*.

Exp. While *ab* is between the parallel lines CD and *nm*, and the current is from *a* to *b*, it proceeds towards some point in CD, and therefore tends to bring *ab* to the position *an*, (*ph.* 12), and when this position is attained, the currents are in opposite directions, and therefore the wires repel each other, (*ph.* 4), and hence *ab* will move towards *a*Q; also while *ab* is on the exterior side of the parallel line *nm*, its current is from a point in CD towards the opposite parts, and will therefore tend to place the currents in the same direction, (*ph.* 12), that is, to cause the wire *ab* to move towards *am*; hence the motion will continue till *ab* coincides with *am*, and the currents being now in the same direction, the wires will attract, (*ph.* 2), and hence the wire moves towards the position *a*D, and the motion is continued as before: thus the wire *ab*, will continue to revolve in the direction from *ab* towards C, *n*, Q, *b'*, P, &c. If the current in *ab* had been from *b* to *a*, it would appear in like manner, that *ab* would revolve in the contrary direction.

PH. 14. The motion of the revolving wire in the last phenomenon is not uniform.

Exp. The forces which cause the revolution, whether attractive or repulsive, are variable, both on account of the different distances of *ab* from CD, and their different

positions to each other, and hence the motion will be variable.

PH. 15. If instead of the single wire *ab*, *fig*. 89, several wires, as radii, proceed from *a*, regularly fixed on that center, the motion will become more uniform, and still more so as the number of the radii, uniformly arranged, is increased.

Exp. It is manifest, that the actions between these radii and CD, tend to turn the system the same way, and will, in this case, be reduced to a state more nearly approaching to that of an uniform action, the parts where the action is greatest being compensated by that where it is least.

PH. 16. When a circular plate is substituted for the wires, such that it is free to revolve on its centre, the motion of the plate becomes uniform.

Exp. The plate may be conceived to be made up of an indefinite number of radii, and hence the motion will be equable, as will appear from the last phenomenon.

PH. 17. The force of an electric current, passing through a wire, is found to be constant for all the parts of the wire, the wire being uniform, and the current preserved at the same intensity in any given part.

Exp. The intensity remaining the same at a given part, it will be of that intensity in every part, since the same quantity of fluid must pass in equal times through all the portions of the same wire; hence, the attraction or repulsion ought to be the same in every one of these portions.

Action on the Magnet.

PH. 18. If a magnetic needle be duly suspended in its natural position, and a wire, connecting the two ends of the galvanic apparatus, be placed parallel to the needle at a small distance, and the observer be situated at that end of the wire from which the electrical power proceeds, looking towards the opposite end; that is, if he look from the positive to the negative end of the wire; then, the needle, if above the wire, will turn its north pole towards the right hand of the observer, if below the wire, to the left; if the needle be on the right side, in the same horizontal plane with the wire, the north pole will point downward, and if on the left, the north pole will be elevated.

Exp. Let AB, *fig.* 90, be part of the wire, along which the current is flowing from A towards B; the dotted line *sn* representing the magnetic needle suspended above it, the needle being a north needle, (see *sect.* ix. *ph.* 41), then it is manifest, that the several magnetic currents of the spirals, in the under side of the needle *sn*, between it and the wire, are in the direction *ew*, (as may be seen by attending to *fig.* 81,) and consequently the spiral channels are attracted from *w* towards B, and from *e* towards A, (*ph.* 3), and there is also a repulsion between A and *w*, and between B and *e*, (*ph.* 5); hence, on all these accounts, the direction of the currents in the magnet will tend to the new position *e'w'*, and, consequently, the needle takes the position *s'n'*, and will rest when there is an equilibrium between the several currents, (*viz.* that about the earth, that about the needle, and that along

the galvanic wire), and the friction and inertia of the needle. Now, it is manifest, that if the center of the needle were conceived to revolve about the axis of the wire, in the circumference of a circle, whose plane is perpendicular to the wire, the same relation of the currents would remain, so that at half a revolution the needle would have the position *fig.* 91, under the wire, and the other positions stated would manifestly take place. Again, if the current were from B to A, *fig.* 92, and the observer at B, it is manifest, by the preceding reasonings, that the needle above the wire would turn to the position, *fig.* 92, so that still the north end is to the right of the observer, at B, and the other positions would be as above stated.

The same explanation will apply equally to a south needle, for when it is above the wire, its currents are from *e* to *w* as before, by which will be evident (looking at *fig.* 82), with the north pole A to the right; the only difference being, that the course in the spirals verges towards the other end of the needle, a circumstance which cannot make any difference, except a little in the quantity of the deviation of the needle, arising from the obliquity of the spirals.

Ph. 19. The tendency of the actions between the needle and wire, as stated in the last phenomenon, is to place them at right angles to each other.

Exp. This will evidently appear by considering, that when the needle has attained the position *s'n'*, *fig.* 90, the action still remains to deflect the needle, in the same way it has already moved, the obstacle to its attaining the perpendicular position, being the diminished force of its currents when out of its natural position, and its tendency to take its natural position by the action of the earth's magnetism, together with the friction and resistance to the free motion of the needle.

PH. 20. The change of position, or deviation of the needle, will be more or less according to the force of the magnetic and galvanic currents, and their proximities.

Exp. The slightest consideration, in connexion with the two preceding phenomena, will clearly shew the reason of this fact, since effects are ever proportional to their causes.

PH. 21. If the needle be fixed, and the wire at liberty to move, it will move the other way, so that an exactly similar relative situation, between the two, will be assumed.

Exp. This necessarily follows, from the principle of action and re-action, these being equal and opposite; and, indeed, we have here the same relation of the operating causes, and consequently of the effects.

PH. 22. If the wire be placed out of the magnetic meridian, the effect will be diminished or increased, according to the direction of the magnetic current.

Exp. This follows, because of the earth's magnetism, and because the action of the currents is now more oblique, either diminishing or increasing the action, according to the position on the one side, or on the other.

PH. 23. If the galvanic wire be at right angles to the magnetic meridian, and its eastern end positive, then if the center of the magnet be placed above the wire, and in its natural position, it will retain that position, and if the needle be placed at any angle with the magnetic meridian it will assume its natural position.

Exp. It will be at once seen, that, in this case, the galvanic current coincides with that of the ethereal matter revolving about the earth, and will conspire with it to keep the needle in its true direction towards the magnetic north. This will be rendered still clearer by supposing the center of the north needle AB, *fig.* 81, placed over the wire, with its north end B pointing to the north; for

this position will shew, that the currents between the needle and wire are flowing in the same direction, that is, the spiral current (*ph.* 41, *sect.* ix.) on the lower side of the needle is from east to west, corresponding with that of the wire: the same will appear if the south needle, AB, *fig.* 82, be in like manner placed over the wire, with its north pole A directed towards the north. Also, it is evident, that if the needle be placed obliquely to the wire, with its center situated as before, it will take its natural position: the currents in the needle, on the opposite sides of the wire, being equally attracted towards it, have no tendency to alter the position.

PH. 24. Things being as in the last, except that the center of the needle is now placed below the wire, it is found that the needle revolves through a semicircle, till its north pole points towards the south magnetic pole of the earth.

Exp By placing the needles AB, *fig.* 81 and 82, as before directed, only now with the center below the wire, it will be seen that the direction of the currents of the needles, on the side next to the wire, is in the opposite direction to that of the wire, and hence the needle will turn half round, so that the directions of the currents may coincide, (*ph.* 11), in which case the north end of the needle will point towards the south.

PH. 25. Things still being as in *ph.* 23, excepting that the west end of the galvanic wire is now positive, so that its electric current is from west to east, it is found that the needle takes its position such, that its north end points to the south.

Exp. The electric current in the wire is much stronger than the natural current of ethereal matter round the earth from east to west; hence, this natural current is quite reversed in the immediate vicinity of the galvanic

wire, and consequently the position of the needle must be reversed from that which it had in *ph.* 23; that is, its north end will now point towards the south.

PH. 26. Things being as in the last, except that the center of the needle is now to be placed under the wire, it is found that the needle will assume its natural position.

Exp. The reason of this will be quite evident from the three preceding explanations: the relation of the currents in this case being the reverse of *ph.* 25, and hence the position of the needle will be reversed.

PH. 27. The action of the earth's magnetism to alter the effects of the wire, may be counteracted, or rendered null, by the vicinity of another magnet, properly placed, and in that case the deviations take place as when the needle is in its natural position.

Exp. A magnet may be placed so as to give a needle any direction we please, (*ph.* 117, *sect.* ix.); hence, if it be so placed as to give it a position parallel to the wire, its deviation from this position is due to the action of the galvanic current alone, for the effects of the earth's magnetism are counteracted.

PH. 28. If the earth's magnetism be rendered null by position, or by another magnet, and the center of the needle, having great freedom of motion, be placed near a galvanic wire of great power, the needle will take a position perpendicular to the wire, turning according to directions shewn in *ph.* 18.

Exp. There is always a tendency in the needle and wire to assume this position, (*ph.* 19), and because of the freedom of motion, and the powerful action of the current, (*ph.* 20), this consequence must follow; and if the wire be carried round the centre of the needle, or the center of the needle round the wire, the same relative position of the two will continue.

Obs. A clear idea of the position of the wire, and needle, may be readily obtained by fastening two rods at right angles to one another; *viz.* AB, *fig.* 93 and 94, to represent the wire, with the course of the current marked by an arrow, and *sn* to represent the needle; then a person holding the rod by the marked end A, and the other directed from him, however he places himself, or the rod, in other respects, *sn* will shew the position of the needle, into which it is brought by the action of the electric current when powerful; when the effect is less, the needle *ns* is inclined, so that the end *n* is nearer to the end B, towards which the current flows. To know the direction of the current in a magnet, see *ph.* 41, *sect.* ix. When the person is at the positive end of the wire, and the other end is pointing directly from him, the side next his right hand is called the right side of the wire, and the opposite its left side.

Ph. 29. The galvanic wire may be composed of any metal, and the effects are nearly the same on the needle.

Exp. Any metal is a good conductor of the electric fluid, and hence will convey the current according to the direction produced in the apparatus; and hence, when the current is equally strong, the needle will be equally affected, and after the same manner.

Ph. 30. The electric current appears to act forcibly on no bodies placed in its vicinity, except the magnet, and iron in a state susceptible of magnetism by its influence, which in that case may be considered as a magnet.

Exp. In the bodies not magnetical, which are brought near the galvanic wire, there are no permanent ethereal currents to be affected by the current of the wire, and therefore they are uninfluenced by its action.

Ph. 31. When plates of glass, or other non-conducting

media, are interposed between the needle and the galvanic wire, the effects are not much diminished.

Exp. Suppose a plate of glass to be placed between the wire and the needle, the electric state of the glass will be affected along the course of the wire, and therefore the other side of the glass will be affected along the same direction, as shewn in the charging of glass electrically, (see *sect.* vii.); hence, the current will still be found to proceed on the opposite side, as it did before the glass was interposed.

PH. 32. The effects of the galvanic wire on the needle diminish with the decreasing power of the battery, and with the distance of the needle from the uniting wire.

Exp. When the power of the battery has become less, the current along the wire is consequently more feeble, and therefore its effects on the needle must be diminished; also, when the needle is at a greater distance from the wire, the force of the electric current is less than when it is nearer, and hence in this case also its action on the needle is less effective.

PH. 33. The needle is not affected by the galvanic wire, when the circuit is interrupted by a non-conductor, making either some part of the wire, or placed in the other parts of the apparatus to cut off the current

Exp. This accords with the preceding explanations, since there is in this case no current, its circulating progress being arrested, (see *sect.* viii.), where it will be seen that, in the most energetic voltaic combinations, the intensity of the current is small.

PH. 34. The electric current circulates through the voltaic battery, and connecting wires; for if a needle be placed over the battery, and another under the uniting wire, they will take a position such, as to place them nearly parallel to each other, which shews that the currents are

in opposite directions, as we should expect, on the opposite sides of the circuit.

Exp. In *sect.* viii. it has been shewn, that the electric fluid proceeds through the voltaic apparatus, so that the connecting wire may be placed between any pair in the combination; hence, its course must be in opposite directions in the opposite sides of the circuit, and consequently the needles must take nearly a parallel position, when one is placed above and the other under the current. A connecting wire might be placed between every pair of plates in the series.

Ph. 35. If the uniting wire of a voltaic combination, and a magnetic needle, have taken the position, in respect of each other, mentioned in *ph.* 18, 19, and 28, and as shewn in *fig.* 94, (see *obs.* to *ph.* 28), so that the wire AB is a little above the center of the needle *sn*; and if now the wire be moved parallel to itself, towards either pole at *s* or *n*, that end towards which it moves will be attracted by the wire more and more, as it advances from the center of *sn* towards the one pole *n*, or the other *s*, of the needle.

Exp. The current in the wire, and the several currents in the needle, on that side which is nearest the wire, are moving in the same direction, and hence the currents in the needle, and that in the wire, tend to coincide, (*ph.* 2 and 3), but while the wire is over the center of the needle, the attraction is equal on both sides; and hence, so long as the centre of the needle is retained in its position, the needle will be unmoved, being equally solicited at the one end and at the other, as the arms of a balance; but when the wire is removed from the center of the needle towards either end, that end will preponderate, because the currents in that half of the needle are now nearer the wire, while those at the other end are more remote; and evi-

dently the effect will increase as the wire approaches nearer to the pole of the needle. Thus it is consonant to all the explanations which have been given of magnetism and electro-magnetic phenomena, "that the same point of the wire has the power of attracting both the north and south poles of the needle," which must always happen when the currents are thus flowing the same way.

PH. 36. If while the wire is over either of the poles of the needle, in the position to which it was brought when moved from the center, (*ph.* 35), and if now the needle be turned round on its center in an horizontal plane, so that the pole which was under the wire may be replaced by the other pole, that pole will immediately be repelled.

Exp. In this case the position of the needle is reversed, hence the direction of its currents is reversed, while that of the wire continues in its first direction; hence, the currents in the magnet on the surface facing the wire, and that of the wire, are in opposite directions, and therefore repel each other, (*ph.* 4 and 5); hence, the reason of the repulsion is evident.

PH. 37. If now the needle be moved in the direction of its length till its other pole is under the wire, or if the wire be moved parallel to itself till it is in that position, the repulsion will still take place; so that according to this, and *ph.* 36, the wire repels the poles which it attracted in *ph.* 35; "the same point of the wire attracting and repelling both poles of the needle according to circumstances."

Exp. The directions of the current in the wire, and of those in the needle are still evidently in opposite directions, as in the last, and hence the effect is produced for the same reason, and there is nothing in these attractions and repulsions contrary to what occurs in other cases of attraction and repulsion. The difficulty vanishes when

we consider, that the currents flowing spirally round the needle, (*ph.* 41, *sect.* ix.), are in opposite directions on its opposite sides.

PH. 38. If, when things are as in *ph.* 35, the wire be moved as there stated, the attractive power increases till it approaches the extremity of the needle; it then, as the wire advances further decreases; and if the wire be carried round the end, to the lower side of the needle, still keeping its central point constantly towards it, the attraction will be nothing when the wire is exactly opposite the extremity in the same horizontal plane with the needle; as the wire descends repulsion commences, and continues to increase as the attraction decreased on the other side of the horizontal plane.

Exp. All these effects are exactly in accordance with the preceding explanations, and confirm them. While the wire is above the needle the currents are the same way; at the pole of the needle the effect will be greatest, (*ph.* 35); when the needle is brought into the same horizontal plane with the wire, the currents on the needle on any of its opposite sides have exactly opposite relations to that of the wire, and therefore exactly counteract each other's effects; and the needle being below the wire, the currents are opposite, and hence produce the repulsion.

PH. 39. If the magnetic needle and wire, as noticed in the preceding phenomena, be so circumstanced, that the magnet is fixed, and the wire free to move, this last will arrange itself at right angles to the magnet, according to the same relative positions of the poles and currents, as above stated.

Exp. The actions of the currents tend equally as before to bring the wire and needle into these positions, which will consequently equally take place, which ever of them is free to move, with the same facility.

Ph. 40. If a magnetic needle be suspended vertically with its north pole downwards, it is attracted by a horizontal galvanic wire, when it is on the right side of the wire, (see *obs.* to *ph.* 28), and repelled when on the left side.

Exp. In the first case the currents in the needle and wire are in the same direction, and therefore attract each other, (*ph.* 2 and 3). In the second case they are in opposite directions, and therefore, (*ph.* 4 and 5), they repel each other.

Ph. 41. Things being as in the last, if either the direction of the current in the wire be inverted, or that remaining, if the needle be suspended with its south pole downward, the reverse of the last phenomenon will ensue.

Exp. In this case one of the currents and only one is reversed, and hence, (*ph.* 9), an opposite effect is the necessary consequence.

Communication of Magnetism.

Ph. 42. If AB, *fig.* 93, be a galvanic wire, in which the current flows from A to B; and if a tempered steel wire or needle *sn*, not magnetised, be placed according to the position represented in the figure above the wire, and then drawn backward and forward in the direction of its length, it becomes a magnet, of which *s* is the south, and *n* the north pole.

Exp. The electric current falling on *sn* on the side facing A, and with the greatest force under it, will cut passages across the needle, descending from the part

towards A, and proceeding under towards B, and this will be effected the whole length of the needle by drawing it backward and forward, and still more completely if sn be at the same time made to revolve on an axis passing through its extremities, because in this case every side is channelled similarly; hence the wire or needle is prepared for admitting ethereal currents around it, descending on the east side, and rising on the west, when sn is placed north and south, as the letters indicate, and it thus, as in *ph*. 41, *sect*. ix, becomes a magnet.

Ph. 43. If the steel wire or needle be placed longitudinally on the galvanic wire, it does not in general acquire permanent magnetism.

Exp. Because the current flows lengthways equally on both sides of the steel wire, it will be evident that channelled passages cannot be cut transversely, the tendency being to form them, only in the direction of its length on both sides, which cannot be effected but through short spaces, and hence the needle does not acquire the disposition of its atoms requisite to admit the spiral current of ethereal matter.

Ph. 44. If a portion of the galvanic wire be twisted into a spiral form, either descending from A to the right, as in *fig*. 81, when the wire is placed horizontally pointing from the nearer end A, towards the remote end B; or to the left, as in *fig*. 82; and if the steel wire or needle be placed in the spiral, it instantly becomes a magnet, the end which the current enters, being in the first case a south pole, and in the second a north pole. The spiral may be formed round a glass tube, and the needle to be magnetised placed within the tube.

Exp. This exactly corresponds with the other phenomena, and is explained as *ph*. 112, 113, and 114, in *sect*. ix. The rapidity of the action arises from the several

turns of the spiral, acting in concert quite round the needle, and producing also a similar action in the parts situated between them, through the medium of the air. In the first kind of spiral a north, and in the second, a south magnet is produced.

Ph. 45. If one part of a galvanic wire be made into a spiral twisted one way, and another part into a spiral twisted the contrary way, and a steel wire or needle to be rendered magnetical be placed in each, both will become magnets having their like poles towards each other.

Exp. This is explained precisely as *ph.* 44, each spiral having its own separate effect as before.

Ph. 46. If the galvanic wire be formed into three spirals near each other, the two extremities twisted in one direction, and that occupying the middle in the contrary way, and if a long steel wire or needle be put within it, so as to extend through all the three; it becomes a magnet having six poles, two for each spiral.

Exp. This evidently depends on the same principles as already developed, and admits of no difficulty, when we consider that the steel wire is susceptible of consequent points, (see *ph.* 65, *sect.* ix). Thus by twisting several parts of the conducting wire, various poles may be given to the same needle.

Ph. 47. If a needle, already magnetical, be placed in the spiral, so that its north pole may occupy the situation, in which by the preceding phenomena it would have been a south pole, after being awhile submitted to the galvanic action, its poles are found to be reversed.

Exp. The reason of this fact is very evident, since the magnetism of the needle, according to the several methods of communicating that power, will be first destroyed, and then regenerated in the contrary sense.

Ph. 48. If the needle to be magnetised as in *ph.* 44, be

not very hard, it need not have its whole length placed within the tube or helix, but will be rendered similarly magnetical, when only the half, or a little more is inserted.

Exp. The one part being rendered magnetical, the other becomes so, when the steel is not very hard, in the same manner as the parts of a magnet, when cut transversely through its center, become magnets, (*ph.* 71, *sect.* ix); and the more readily in this case, because the circumvolutions of ethereal matter through the conducting helix, extend beyond each of its extremities.

PH. 49. If the conducting wire be coiled into a flat spiral as *b*, *c*, *a*, *fig.* 96, and the steel bar *ab*, not magnetised, be placed on it over the center; the bar will be magnetised, so that it will have a magnetic pole at the center, and the opposite ends will acquire contrary poles.

Exp. It is manifest that the electric current in the galvanic spiral wire traverses the steel wire in different directions, on the opposite sides of a line *cd*, cutting the bar at right angles at the center; hence the course of the channels, cut in the bar or steel wire, will be on the same side upwards in the one half, proceeding from the center to the end, and in the other half, likewise from the center downward; from which it is seen that the ends ought to be similar poles, and therefore the contrary pole will be at the center.

PH. 50. If the current proceed from P to the center, and thus be carried round as denoted by the arrow heads, passing to the cup N connected with the negative end of the battery; then, supposing the person looking from *a* to *b*, if the bar be on the left side of the spiral, *a* and *b* are north poles; but if the bar be on the right of the spiral plane, *a* and *b* are south poles. If the connection of the spiral with the battery be changed, so that the current

passes through the spiral in the contrary direction, then the reverse with respect to the poles will result.

Exp. Suppose *ab* is placed north and south, and on the left of the spiral, then the part *ob* of the bar, is cut on the east side descending, and advancing northward, that part is therefore a north needle of which *b* is the north pole, (*ph.* 41, *sect.* ix). Again the part *ao* is cut on the east side ascending obliquely from *o* to *a*, therefore it is also a north needle of which *a* is the north pole; for looking from *o* towards *a* the part *ao* will be cut similarly to the other part. Next let the bar be on the right of the spiral plane; then the west side of the part *ao* is cut obliquely upwards proceeding from *o* to *a*, it is therefore a south needle, of which *a* is the south pole (*ph.* 41), and similarly it may be shewn, that *b* becomes a south pole of a south needle. A like explanation will apply when the current is reversed.

Ph. 51. The bar *ab* lying on the plane of the spiral, as in *ph.* 49 and 50, if it be now drawn gently forward according to the direction of its length, becomes a magnet having two poles of opposite names, one at each end as usual; that end which was first drawn from the spiral plane retains the polarity which it had acquired, and the pole at the other end is reversed.

Exp. As the bar is drawn along, it is evident that the channels cut in its surface remain on the part first separated, but the other half, after its parts pass the center of the spiral plane, will have their channels reversed, because the current in the conducting wire is in the contrary direction, and hence the reason of the fact is evident.

Obs. It will be seen, that this method of magnetising a steel bar, is analogous to that of the single touch (*ph.* 76, *sect.* ix) by a magnet.

Ph. 52. Instead of placing the steel bar on the flat

spiral, as above directed, let it be so placed, that its axis shall be perpendicular to the plane of the spiral, and resting on its center, the bar will still be magnetised.

Exp. Since the current in the spiral wire, and contiguous air, revolves about the adjacent end of the bar, it renders it magnetical, and, if time be allowed, the magnetism is propagated throughout the bar, the part first magnetised facilitating the process, as in *ph.* 57 and 58, *sect.* ix, to which this is perfectly analogous.

Ph. 53. If the bar be very hard, it will be found to acquire a series of consequent points; but when it is not very hard, and of a small length, it acquires two poles as usual.

Exp. This is explained as *ph.* 65, *sect.* ix, to which it corresponds.

Ph. 54. If the bar *ab*, *fig.* 96, be placed at right angles to the plane of the flat spiral, having its end *a* at the center *o*, and if the current be moving through the spiral, in the direction marked by the arrow heads in the figure, that is, from the center to the extremity *d*, the end *a*, which is in contact with the spiral, is a north pole of a south needle, or the south pole of a north needle; but if the current flow in the contrary direction, that is, from *d* through the circumvolutions to the center, the point *a* will have a contrary polarity. If the spiral were twisted in the contrary direction all this would be reversed.

Exp. In the first case, if we turn the apparatus so that the end *b* of the bar shall point towards the south, we shall see that the currents induced in it, descend obliquely on the east side, and rise on the west, advancing from *a* to *b*, therefore *a* is the north pole of a south needle. Again when the current in the conductor is in the opposite direction, turn the apparatus so that *b* shall point to the

north, and it will be found, that the channels cut in the bar descend obliquely on the east, rise on the west, and advance northward; hence, *a* is the south pole of a north needle. Magnetism here is induced by the wire in the first case, precisely as by the terrestrial current in the southern hemisphere. This may be illustrated more fully by drawing a spiral on a card, and sticking a pin perpendicularly on its center; if the lines of the spirals be turned the contrary way to those in the figure, it will be seen similarly that the opposite effect will arise.

Ph. 55. If the steel bar be placed at right angles to the plane of the spiral, with its middle point at the center, so that one half shall be on one side of the spiral, and the other on the contrary side, the bar will acquire poles at its two extremities of the same name, and one of the opposite name at its middle. Thus, if the spiral be twisted, as in *fig.* 96, and the current proceed from the center, the middle point will be a south pole, and the extremes will be north poles, but the contrary if the current move towards the center; and both these will be the reverse if the spiral were twisted in the opposite direction.

Exp. The whole of what is here stated will be clearly understood from the explanation of the last phenomenon.

Ph. 56. Part of the conducting wire of a voltaic combination, being formed into a helix, as in *ph.* 44, will communicate magnetism to a steel needle placed on the outside, in a line parallel to its axis, as well as when placed within the spiral, but the polarity produced is the reverse.

Exp. This agrees with the other methods of magnetising already described, and needs no farther illustration.

Ph. 57. The nearer the needle is to the spiral, the sooner it is magnetised.

Exp. This follows from the greater force of the current in the vicinity of the wire.

Action of a Spiral Conductor.

PH. 58. If part of the conducting wire be formed into a spiral, by wrapping it round a glass tube, about four or five inches long, and half an inch in diameter; and one half of a magnetic needle be placed in the tube, the other half projecting beyond it, as soon as the connection is formed, and, consequently, the galvanic action commences, the needle is drawn towards the middle of the tube, provided it be first placed according to the position in which it would receive, by the action of the helix, the same kind of magnetism which it already possesses.

Exp. Let AB, *fig.* 98, be a spiral placed horizontally, pointing from you towards B, to which the current flows, and containing the tube, in which is *sn*, a north magnet, placed as in the figure, then the spiral course of the ethereal matter in the magnet agrees with that of the galvanic current in the spiral, (*ph.* 44), and first let it be placed half its length within the tube at the end A, then the ethereal matter, entering the exposed part of the magnet at *s*, tends to urge it in the direction *sn*, or AB, the equal and opposite action of the ethereal matter escaping at the other half towards *n*, and which tends to carry it in the direction *ns*, is counteracted by its concurrence with the galvanic stream in that part which is in the tube; therefore the needle will move towards B: when the needle is placed at the other end, as in the figure, the entire action in the direction *ns*, or BA, remains the same, while that in the opposite direction, *sn*, or AB, is counteracted by its coincidence with that of the galvanic current, hence it will move towards A; therefore, it will only rest at the

middle or center of the tube, where the forces are equally diminished on both sides, since in every other part the action will be unequal, because the spiral vortex extends beyond the end of the magnet. If the needle be at first free from magnetism the same will happen, because when in these positions, the needle is at once magnetised, having its poles as here placed. The same explanation serves when the spiral lines of the wire turn the contrary way, a south magnet being used, or formed, or a north magnet in the opposite position.

PH. 59. Things being as in the last, if the spiral and tube, with the included magnet, be held vertically, the needle will remain suspended at the middle of the tube, in its axis, while the galvanic action continues to be energetic, so that it seems to be supported in the air.

Exp. The needle remains suspended in this case for the same reason that it assumed the middle, as shewn in the last phenomenon, and it is not wonderful that this force should exceed that of gravity, on a small needle, since the ethereal matter is in constant motion, and is acting in myriads of points to prevent its falling: also, it is evident, that the position of the needle must be that of the axis of the tube, since the action of the current is equal in the spiral on every side of the tube, and its own weight directs it downwards only.

PH. 60. If the needle be placed in the tube in the opposite position to that mentioned in *ph.* 58, it will be thrown out again immediately. It is necessary to make the experiment dexterously, and with rapidity, otherwise the polarity of the needle will be reversed, and the contrary effect will ensue.

Exp. The action on that part of the needle which is without the tube is the same as mentioned in *ph.* 58, but that within the tube is now increased by the repulsion of

the opposite currents, and the repulsion continues till the poles are by its action reversed; hence, if at liberty, as soon as inserted, it will be immediately expelled.

Ph. 61. If the spiral be placed in a basin of water, so that the axis of the glass tube about which it is wrapped, and which may be about three-fourths of an inch in diameter, is made to coincide with the surface of the water, and the needle made to float by means of a small piece of cork, it will be agitated, and arrange itself, at the end to which it is nearest, parallel to the axis of the tube, and then dart into it, moving nearly to the other extremity, it then returns, and thus oscillates, till it becomes stationary at the middle of the tube. The pole of the needle, which enters the tube, answers to that which the spiral would have given it, and this agrees with what is noticed in *ph.* 27.

Exp. The two last phenomena shew the reason of this, as will appear from attending to the direction of the currents.

Ph. 62. Suppose the wire twisted into a spiral, according to the direction in *fig.* 98 or 81, that is, the same as the spiral in a north magnet; then if the floating magnetic needle be near the negative end of the spiral, which receives the current, its north pole will enter into the tube, if its south pole happen to be nearest to that end, it will be repelled, the needle will make half a revolution, and then dart into the tube: the reverse takes place when the needle is near the positive end of the spiral. If the spiral had been twisted in the opposite direction, as in *fig.* 82, the preceding results would have been reversed.

Exp. The correspondence of these effects, with those which have been already explained, renders the reason quite obvious.

Ph. 63. A neat electro-magnetic instrument was con-

trived by M. *De la Rive*, and may be thus formed: a piece of zinc about two inches long, and half an inch broad, is passed through a cork, through which also passes a slip of copper of the same breadth, and turned round the zinc below, so as to face both its sides. A piece of copper wire, covered with silk thread, is coiled five or six times round, so as to form a ring, of about an inch in diameter, one of its ends is soldered to the copper, and the other to the zinc above the cork. This apparatus, if placed to float in water, slightly acidulated with sulphuric, or nitric acid, will produce the galvanic current, and the ring will take a position perpendicular to the magnetic meridian. The instrument is more steady in its assumed position, if the zinc and copper combination be inclosed in a small glass cylinder to contain the acid, and then floated in water.

Exp. The galvanic arrangement of zinc and copper, with the acid solution, produces an electric current from the surface of the zinc through the liquid to the copper, and from that through the coiled wire to the interior of the zinc, and, because of the oxidation of the zinc surface, the current is kept up as explained in *sect.* ix. Now it is evident that the current cannot coincide with that ethereal matter, which constantly revolves about the earth, but when it attains the position in which the ring is perpendicular to the magnetic meridian; hence, it will assume this position.

Ph. 64. If the wire be coiled according to the directions of the spirals of a north needle, *fig.* 81, the end of the ring, at which the wire is joined to the copper, will be directed towards the south, but if it be coiled in the contrary direction, that end will be northward.

Exp. The side of the ring on which the current descends ought to face the east, as shewn in *ph.* 41 and 43,

sect. ix; hence, the instrument will tend to take this direction, in which its current and that of the earth may coincide.

Ph. 65. The wire ring of the apparatus described in *ph.* 63, possesses other magnetic powers, being attracted and repelled by a magnet in many respects as one magnet is by another: a wire thus or otherwise coiled spirally round, so as to form a sort of cylinder, has been denominated the dynamic cylinder; I should prefer the term electric cylinder, because an electric current is passing through it, while it is capable of exhibiting its influence on the magnet. If the north pole of a bar magnet be presented to the positive end of the spiral, or coiled wire, described *ph.* 63, it is attracted, if the spiral be coiled according to the direction of a north needle, *fig.* 81, but the negative end is attracted, when the spiral is twisted as a south magnet, *fig.* 82. The contrary happens if the other end of the magnet be presented, or if the same end be presented to the contrary end of the electric cylinder.

Exp. All these actions agree with the explanations of *ph.* 117 and 118, *sect.* ix, from which, with those of *ph.* 2, 3, 4, and 5, of this section, the reason of these actions will be obvious.

Ph. 66. If that side of the spiral ring which is attracted, be near the magnet, placed horizontally, the ring advances slowly, till it envelopes the magnet, and then is accelerated till it reaches the center of the magnet, where it remains stationary.

Exp. This is a natural consequence of the attraction, which is much stronger when the pole of the magnet is within the ring: it rests in the middle, because at the other end repulsion would ensue.

Ph. 67. If the end of the magnet be placed within that end of the ring at which there is repulsion, the ring goes

off to some distance, turns half round, and then advances again, and settles itself as before, at the center of the magnet.

Exp. The ring recedes on account of the repulsion, and as that end is repelled, and the other attracted, the ring is turned about, and then proceeds as before described, till it gains the position of equilibrium.

PH. 68. The electrical cylinder possesses the general properties of the magnet, yet there are some differences. Thus the poles of a magnet are at some small distance from the ends, but in the electric cylinder the poles are at the extremities.

Exp. The cylinder receives the electric current from the positive wire at the one extremity, and delivers it to the negative wire at the other extremity; on the contrary, the magnet receives its current around the sides on one half from its center, and delivers it at the sides of the other half, and this is sufficient to account for the difference mentioned, and some others: the obliquity of the ethereal currents near the poles of a magnet, as represented in *fig.* 85, will also occasion several differences.

Magnetism of a Conductor.

PH. 69. If a quantity of iron filings be strewed over a piece of paper, and the conducting wire of a powerful battery be placed over them, they will be attracted by it: if the flat spiral, *fig.* 96, be held over them with its plane parallel to the paper, a very great quantity of the filings will be raised.

Exp. In consequence of the electric current, especially

in the spiral conductor, the filings are rendered magnetical, as in *ph.* 41, 47, 57, &c. *sect.* ix; hence the reason of the effect is evident.

PH. 70. Filings of copper, or any other metal, not susceptible of magnetism, are not attracted by the conducting wire.

Exp. Since these filings cannot acquire magnetism, it is evident that they cannot, by means of the current, acquire the power to attract each other.

PH. 71. "The center of force in a magnet having a free horizontal motion in every direction, (floating on water), is at the center of its magnetic axis; which attaches itself to a vertical conductor in the case of attraction, but removes from it indefinitely in the case of repulsion." Thus, if the plane of the conducting wire *a, b, c, d, e, fig.* 99, be placed at right angles to the magnetic meridian, the current entering at the western side *a*, the needle when placed to float on the exterior of *bcd*, will move to that wire which is nearest, in such a manner that its center shall adhere to the wire, and it will there remain at rest.

Exp. When the needle is between *g* and *b*, the currents in the wire, and in the needle on the side next to the wire, are both descending, and when between *f* and *d*, they are both ascending, hence arises the attraction (*ph.* 2 and 3), and if the center of the needle be north or south of the wire, the attraction at the larger part is greatest, hence, the equilibrium can only be maintained at the center of the magnet.

PH. 72. Things being as in the last, if now the direction of the current be changed, *viz.* from *e* through *dc*, &c., the needle, when placed in the interior between *bc*, and *dc*, will be attracted to the nearest wire, to which its center will adhere.

Exp. The current in each wire, and those in the adjacent sides of the needle are now also in the same direction, and hence the effect is produced as before.

Ph. 73. The current, and other things being as in *ph.* 71; if now the needle be placed in the interior of the wires, between *bc*, and *dc*, it will move northward or southward according as its center is on the north or south side of the plane *bcd*, it will then turn round, and pass to the exterior side, and then move forward and backward, till it rests with its center in contact with the wire.

Exp. While between the wires *bc*, and *dc*, it is repelled by both, hence if its center be without the plane of the wire, it must be thrown out from between its branches, and the attraction from the opposite side turns it round: the remaining effects are as in *ph.* 71.

Ph. 74. If, while the needle adheres to the wire, as in the last, the current be reversed and made to enter at *e*, it will be seen, that the needle is repelled from the exterior part, and turning about, it enters the interior, and is soon attached to the wire as before.

Exp. The reason of this will be evident after reading the three last explanations.

Ph. 75. Let *abcdef*, *fig.* 100, be a conducting wire, having the points *a* and *f*, in the same vertical line, inserted each in a small cup of mercury, one of which is connected with the negative, and the other with the positive end of a voltaic arrangement, and let its plane be situated before the spectator; then if a strong magnet be placed so that its center may coincide with that of the ring *bcde*, and if, when the current is from *a*, through *bc* and *e*, the north pole of the magnet be on the farther side of the plane, or, when the current is the contrary way on the nearer side, the ring will remain at rest, if the axis of the magnet be perpendicular to the plane of the

ring; but if it be a little inclined from the perpendicular, the ring will move about its axis to the sides of the magnet on which is the acute angle.

Exp. The current in the parts of the conductor, and those of the adjacent sides of the wire, are in the same direction, hence, the magnet is attracted on all sides, and equally, when its center coincides with that of the ring, and its axis is perpendicular to its plane, but when oblique the attraction is strongest at the two acute angles, and hence the ring will approach the magnet on those sides.

Ph. 76. Things being as in the last, if now the poles of the magnet be inverted, while the course of the current remains the same, the ring will place itself so that its plane shall be at right angles to the axis of the magnet, whatever angle it makes with it at first.

Exp. Here there is evidently repulsion at all the four angles, because the currents are opposite, but when the magnet is inclined to the plane of the ring, the repulsion is greatest in the acute angles, hence the reason of the effect is evident, since there can be no permanent equilibrium, but when in the above mentioned position.

Action of a Conductor on Mercury.

Ph. 77. If two wires from the opposite ends of a voltaic circuit with large plates be placed perpendicularly in a basin of mercury, and if a powerful magnet be held above or below either of the wires, the mercury revolves, forming a vortex about the wire as an axis; the velocity is increased, if the opposite poles of two magnets be placed, the one above, and the other below the wire.

Exp. While the magnet is held in a line with the wire, or still more when the opposite poles of two magnets are placed the one above, and the other below, in the direction of the perpendicular part of the wire, the spiral or vertical current, which revolves about the magnet or magnets, (*ph.* 41, *sect.* ix.) communicates its motion to the fluid mercury, as it does in other cases to the air, and this agrees perfectly with *ph.* 117, and 68, *obs. sect.* ix, where similar motions are indicated.

Ph. 78. Things being as in the last, if now the magnet be held above the mercury in the middle between the wires, the circular motion ceases, and currents are produced, the one to the right, and the other to the left of the magnet.

Exp. The magnet being now perpendicular to the current in the mercury between the wires, that current is affected by the revolving current of the magnet, which causes the observed disturbance in that liquid.

Ph. 79. If two thick copper wires be cemented into two holes, about 3 inches apart, in the bottom of a shallow glass vessel, the wires being coated with sealing-wax, except at the ends which are to be made flat, and polished; the basin being now filled with mercury to $\frac{1}{11}$ of an inch above the ends of the wires, which are to be placed upright, and connected with the extremities of the battery; it will be found that, when the circuit is completed, the mercury rises to $\frac{1}{5}$ or $\frac{1}{6}$ of an inch above each wire in the form of a cone, and, if the action be strong, waves flow in all directions from the cones, the point of rest being near the center between the wires.

Exp. The repulsion between the quicksilver and the ethereal matter, constituting the electric current, and passing from the positive wire to the mercury, and, again from the mercury to the negative wire, elevates the liquid;

especially as it is necessitated to leave the one wire, and to enter the other at the end; hence the conical elevation is produced, as is the motion of the wire in *ph.* 1, or as the electric fly is moved; and as it is raised continually, it must needs flow down on all sides, and produce the waving motion.

Ph. 80. Things being as in the last, if a powerful magnet be placed some inches above one of the cones, its elevation is diminished, and as the magnet is lowered, the altitude of the cone decreases, till the surface of the mercury becomes flat, and a rotation commences slowly about the wire.

Exp. The action of the magnet tends to produce a vortex in the mercury as in *ph.* 77; hence, when the magnet is powerful, it depresses the conical elevation, and produces the circulating motion.

Revolving Motions.

Ph. 81. The pole of a magnet will move round a conductor, if not prevented by intervening objects, and the motion will be according to the order pointed out in the preceding phenomena (see *ph.* 18, and following). Let CD, *fig.* 101, be a non-conducting vessel containing mercury, with which the wire A communicates, and into which the wire B dips about half an inch. Now, if a magnet *sn* be attached by a thread *s* to the wire A, so that its north end *n* may reach a little above the mercury, while the wire B is fixed; when the connection is

made with the voltaic apparatus, by joining A to the positive, and B to the negative end, the magnet will revolve about B in the direction denoted by the arrow heads marked on the circumference of the circle, which is drawn about B the fixed wire.

Exp. Let the experimenter have the apparatus before him, and first let the magnet be between him and the wire B; then the current in B is upward, as shewn in the detached figure by the arrow head on *ab*, and the parts of the spirally revolving current, in *sn*, on the side next to B, are in the direction *cd*: hence there is an attraction in the angles *dob*, and *aoc*, and a repulsion in the angles *boc*, and *aod*, (*ph.* 7), therefore the tendency is to bring the magnet *sn* to the position in which its north pole *n* may be to the right, and consequently, from the circumstances of the connection, *n* must move to the right as marked by the nearer arrow head on the circle; but this relation of the currents remains on every side of the wire, as may be seen by placing *sn* on the farther side of B, and using the detached figure where $c'd'$ shews the direction of the parts of the current on the side of the magnet next to the wire; from this it is evident, that a continued revolution must take place, the freedom of the motion being sufficient for that purpose. The above reasoning holds good whether *sn* be a north, or a south magnet.

Ph. 82. If the magnet be so attached that its south pole may be uppermost, its revolution about the wire will be in the opposite direction: also if the direction of the electric current in B be reversed, the motion will likewise be reversed.

Exp. The reason of all these effects is evident, when we observe that the relations of the currents in the magnet and wire become exactly opposite in consequence of these changes.

PH. 83. Conversely, if the magnet be fixed, and the wire free to move, it will revolve about the magnetic pole; if the electric current be from A to B, (*fig*. 101, *sn* being supposed upright), the wire B will rotate about *n*, as marked on the circle, and will be reversed by reversing the magnet, or the current, but will continue the same by reversing both.

Exp. This is a necessary consequence, as will appear from the two last, action and re-action being equal and opposite: or the same may be explained by considering the relations of the currents as above.

PH. 84. If both the wire, B, and the magnet, *sn*, *fig*. 101, be free to move, they will revolve about each other according to the law above stated, each in a conical surface, of which the common axis is the line joining the wires A and E.

Exp. The three last phenomena render this sufficiently clear.

PH. 85. Let *ab*, *fig*. 102, be a section of a channel cut in a board, and *w* the section of a wire suspended freely by a loop, from an upright fixed on the same board, reaching down so far as to dip a little into some pure mercury put into the cavity *ab*; SMN a section of a horse-shoe magnet placed on the same board, as in the figure, S being the south, and N the north pole: now if the ends of the voltaic apparatus be connected in such a manner, that it would cause the wire to rotate about the north pole, as denoted by the arrow heads on the circle *de*, (see *ph*. 83); the wire will in this case be projected out of the mercury towards *a*, and, as it falls back, will continue to be repeatedly thrown out, if the position of the magnet, or the course of the current were reversed, the wire would in like manner be projected towards *b*, but the effect would remain as at the first, if both were reversed.

Exp. In the first case the wire would tend to revolve about S according to the direction marked on the circle *fg*, hence evidently by the joint action of the magnetic poles the wire will be thrown towards *a*. The other cases being converse, will be easily understood from *ph*. 81, 82 and 83.

Ph. 86. If instead of the wire *w*, a thin copper wheel, made capable of revolving easily between two branches, *nm*, *fig*. 103, of a fixed wire, be so placed, that the tips of the wheel shall be slightly immersed in the mercury in *ab*, *fig*. 102, the surface of the mercury being covered by very dilute nitric acid; the wheel will revolve, when the electric current is made to pass through it, as in *ph*. 85.

Exp. Let the connection be such as in the first case of the last phenomenon, then the points of the wheel which are towards *b*, are attracted towards *w*, and those which are on the side next to *a* are repelled, as shewn before, the points on the lower side moving towards *a*; hence a continued rotation is the consequence, which as before may be reversed.

Action of Terrestrial Currents.

Ph. 87. If the flat spiral be suspended in cups as at N and P, *fig*. 96, each containing a little mercury, and so that the spiral may freely move on the axis NP, when the connection is made from N and P with the voltaic battery, the spiral will assume a position, such that its plane will be perpendicular to the magnetic meridian of the place, and that part of the spiral in which the current descends, shall face the east.

Exp. This agrees perfectly with what is advanced concerning the magnet in *ph.* 41, &c. *sect.* ix, and ought to take place, because the ethereal current of the earth and that of the spiral agree.

Ph. 88. Professor *Hanstein* found, that all lofty vertical bodies affect the magnetic needle, indicating that they have a south pole at the top, and a north pole at the bottom.

Exp. This exactly corresponds with what we have already shewn, that an electric current continually, in high latitudes, tends towards the earth.

Various other phenomena relating to this subject have been elicited by the labours of *Oersted, Davy, Faraday, Ampere, Biot,* &c. &c. See Mr. *Cumming's* translation of M. *De Monferrand's* Manual of Electro-dynamics, and Mr. *Barlow* on Magnetical Attractions, with other similar works. They may all be explained by means of the five first phenomena of this section, as well as those curious effects called Thermo-electric, first noticed by Professor *Seebeck.*

CONCLUDING REMARKS.

Of all the departments of natural philosophy, that of physical astronomy, at the first sight, would seem more than any other to be placed beyond the reach of our faculties; but it is well known that there is none in which we have advanced with so much success, and demonstrative certainty; for this we are chiefly indebted to our illustrious countryman *Newton*. From the exposition of the laws of one single agent, the force of gravitation, all the movements of the solar system are developed, as well those of rotation, as those which relate to their periodical revolutions, and even the anomalies, and apparent irregularities, are under the dominion, and controul of this power. Now since we are satisfied of the existence of the principle of gravitation, and admit that it affects every atom of matter, we ought to examine the actions of bodies on each other at minute distances, with the view of finding what part of these actions is attributable to gravitation.—Philosophers seem to have agreed to discard the operation of this force, except at sensible distances; but if gravitation be not the sole agent, it must needs, at these exceedingly small distances, act a very distinguished and important part, in producing the changes, which are constantly going on in nature. Do not lose sight of gravitation;—and, by pursuing this thread, you will be guided through the mazes of a most intricate labyrinth, to a situation exceedingly near the seat of its activity. Here it will be seen that the whole mass of force presents its resistance equally, uniformly, and with immense effect, on

every side; consequently this center has every property of a solid substratum, and there is no imaginable use, as far as we can perceive, for a solid nucleus, which is not answered by this concentrated force, this itself forms the solid part of matter. It is not here supposed that force acts against nothing, but against another opposing force: we know nothing of *matter*, but by the forces which it exerts, and which doubtless constitute its nature. Does any one ask,—What is matter, and what is force? It may be answered,—Matter is force applied, and exerted in a peculiar way: and reciprocally force operating in a certain mode, constitutes matter. Is the inquiry pursued,—What is this force applied and exerted so as to constitute matter? We cannot tell what is its essential nature, more than this, that it is a power acting against a similar power, and may be greater or less than the other, or equal to it, being as far as it respects matter, a wonderful act of the Ever-living God, who worketh all things according to the counsels of His Will. Every atom of matter, as will be seen from the view we have given of it, was created or brought into existence by an operation of the Almighty Power of God, and continues to exist by His continued act, either immediate or mediate; for the same power, which first produced this substance, is requisite to sustain or uphold it in existence. The inconceivable myriads of atoms, which are contained in bodies, tend to excite astonishment, and present before us an inexpressible sublimity. Here we see the act of creation and conservation; and, when we extend our views to the innumerable huge bodies, which compose the universe, and to the multiplied millions of millions of atoms in each, with the united actions of their concentrated forces; we are prepared to say, that Power belongeth to God alone.

There is no less evidence of supreme Wisdom in the

structure of matter: the law of force, which constitutes its actions, is adapted peculiarly to preserve the existence, and constant harmony of the universe. The same law of force is equally subservient to maintain the beautiful order, and motions of systems of worlds, and to regulate the various changes and modifications, which bodies and atoms are designed to undergo, in their connections and combinations with each other. The all-powerful hand of the Creator could certainly have constituted matter with forces varying by other very different laws, but we can conceive of none, which could have so completely answered the great ends of creation in the constitution of the universe, and the regulations and organizations of its several parts. The same Wisdom is seen in the variety of the atoms of matter, and the proportions of each sort, none are in defect, none in excess; and from the nature of their constituent forces, there is a constant tendency to preserve the established order of things, according to an All-wise and Infinite design. We are easily led to perceive, that it was in the mind of the Creator to form beings more elevated in nature than mere matter; hence, he has superadded a principle, superior to that which has been the subject of this Treatise. I mean vegetable life. This, whatever it is, is associated with the seed of the plant, and directs the combinations of common matter, when put into suitable circumstances, according to the nature and species of the vegetable which is to be unfolded and matured. The principle of animal life is still more dignified. This principle is hid in the ovum, as that of the vegetable is in the seed. It directs the growth of the animal, as well as the peculiarities of its shape, and organs; and the developement of these, reciprocally aids the principle itself, which becomes capable of supporting, and directing wonderful movements, actions, and

instincts. The result shews, that the Omnipotent Creator had purposed to form a being, who should possess a nature far more transcendent than that of the mere animal; one possessing an intelligent mind, capable of surveying His works, and of rising from the survey of these to their Great Author. This did not escape the notice of the Roman poet, as stated in those well known lines.

Sanctius his animal, mentisque capacius altæ—
* * * * * * * *
Finxit ineffigiem moderantûm cuncta Deorum.
Pronaque cùm spectent animalia cætera terram,
Os homini sublime dedit; cœlumque tueri
Jussit, et erectos ad sidera tollere vultus.

Ovid. *Metam.* lib. i. l. 76.

The material part of the earth is adapted to nourish and maintain the vegetable world, and this serves to support the animal kingdom, while the whole contributes to the maintenance and pleasure of man in his present state. But the intelligent and rational principle is capable of more elevated enjoyments and exercises in the pursuit of truth, and the discernment of right and wrong; and still more, in yielding due homage to his Creator, and in presenting cordial expressions of gratitude, veneration and worship.

It is very observable, however, that some disorder has affected the human race. We search in vain in the book of nature to ascertain either the cause or remedy of this evil. Revelation alone furnishes this most important of all knowledge. The Sacred Scriptures shew us the path of life, and direct us in the right use and management of nature in general, as it respects the promotion of our present and future felicity.

NOTES.

NOTE A.

Postulate 1, *page* 3. Should an objection to this postulate be raised, on the ground, that force cannot act unless it has something to act upon, the objector should notice that no such supposition is here made, a force is supposed to act not against nothing, but against another force. We know nothing of force as acting on matter, more than that of its effects in changing the state of that matter. Hence we only know it in the action of one power against another; now if equal powers act in all opposite directions from a given point, there will be an equilibrium on all sides. Therefore, the notion which this postulate gives of an atom of matter, is not a force acting against nothing, but a balance of forces on every side of a central point, and this is all we can understand of it, whatever substratum we may imagine to exist; for it is nothing but mere hypothesis, the effect of imagination, and a vulgar notion, to judge, that there is a minute solid impenetrable mass necessary to constitute an atom of matter on which forces act. I am aware that this notion has been admitted by philosophers of the first rank, but we know nothing of such little solids, we have never seen them, nor felt them, nor perceived them by any one of the senses; if they do exist at all, we have not been affected by them, but only by the

forces of repulsion and attraction, directed in one case from them, and in the other towards them. If any one however wish to retain these solids, he has my hearty consent and sanction; this theory will suffer nothing by the concession, only he must necessarily admit, that they are incomprehensibly small, and he must grant also as much as the two postulates require, in respect to the existence of attraction and repulsion of every atom of matter; or, if not, he must give up all pretensions to philosophy. There appears in fact to be no use whatever for these infinitely small solids, and it is on this ground that I discard this ideal substratum. The centers of atoms, as described in this postulate, are strictly speaking the solid parts; for the whole force of the atom is at this point concentrated, and is therefore infinitely greater, than at any point in the surface of an imaginary sphere, described about the same center of the atom at any finite distance.

In order to assist the mind in forming a correct idea of this postulate, take two small spheres, as two marbles, or two beads, and imagine, that if *the center* of one of these were placed *within the surface* of the other, it would be repelled by that other atom; but while *its center* remains *without the surface* of the other, it will be attracted; and that whether it is attracted or repelled, the force is always greater in the ratio of the square of the diminished distance; and by the help of these symbols you may depict in your minds the nature of the atoms of matter. Every *Newtonian* consents to all that is difficult in this postulate; the only difference is, that here the forces are considered as constituting the essence of matter, while otherwise it may be conceived as only an appendage.

No one, admitting the first postulate, will withhold his consent from the second. Let the two marbles, used above to illustrate the constitution of atoms, be of unequal magnitude, then they would represent two different kinds of atoms, even if the force of each were the same at a given distance from the center; but, this difference remaining, the force of the smaller, which is the symbol for the atom having the less sphere of repulsion, may be either greater or less than that of the other: also two atoms whose spheres of repulsion may be equal, may yet be very unequal in force, hence very great differences will arise, sufficient to account for the great varieties in bodies.

These differences will authorise the 32nd *definition*, which presents a chasm between the common and the more subtile sorts of matter,

as is indicated in all natural operations. Probably the absolute force of an atom of ethereal matter is millions of times less than that of an atom of tenacious matter, while yet the sphere of repulsion of the former may be either greater or less than that of the latter. Notwithstanding this great difference in the absolute forces of the atoms of these two classes of matter, yet an ethereal atom will adhere to a tenacious one with somewhat more than half the force by which two tenacious ones would adhere. For example, suppose the force of the ethereal atom to be one million times less than that of the tenacious one, which we will suppose is equal to that of one grain at the surface of the sphere of repulsion, then two such tenacious atoms would adhere with the force of two grains, and the ethereal would adhere to the tenacious atom with the force of one grain and the one-millionth part of a grain, that is, with a little more than half the former force. Hence a tenacious atom will, by its constituent forces, retain on its surface an immense number of ethereal atoms, as an atmospherule, if they be presented to its influence; for, because of their small force, their centers will, by the action of the central atom on them, be brought exceedingly near together. Hence, if the force of the tenacious atom were annihilated, the ethereal ones, constituting the atmospherule, would separate with amazing rapidity. The rapid propagation of inconceivable quantities of ethereal matter will in fact occur on various occasions, arising from the innumerable changes which bodies frequently undergo.

NOTE B.

Par. 17, page 67. A little reflection will shew that the relation of the density to the pressure depends but in part on the law of force, and from it therefore, that law can never be determined; the effect will be regulated by the temperature of the exterior gas, and while that remains constant, and time is allowed for the compressed gas to arrive at the same temperature, we may expect, that in a series of pressures, each being equal to the preceding, a proportionate contraction will ensue: if the pressure were carried to an extreme degree, the density would not increase according to the ratio of the pressure. The quotation from Biot states expressly, that the conclusions, respecting the compression and dilation of air, are not exact, if we make the pressures to succeed each other with great rapidity. These considerations will suffice to shew that there is nothing in the compression of gases at all calculated to invalidate the law of repulsive force, which we have assigned to the atoms of matter.

NOTE C.

PH. 22, *page* 70. This phenomenon has been matter of controversy among modern philosophers. A very curious and ingenious theory was proposed by Mr. *Dalton*, of *Manchester*, who is well known as an eminent chemical philosopher. According to him, "The particles of one elastic fluid possess no repulsive nor attractive power, or are perfectly inelastic with regard to each other; and consequently the mutual actions of the fluids is subject to the laws of inelastic bodies." *Thomson's* Chem. vol. iii. p. 84.

This very remarkable hypothesis does not appear to have any evidence to support it, except that of conveniency; on this account, and on this alone, it is worthy of notice; but it is liable to a multitude of objections, and although it explains the particular facts which suggested it, yet it is altogether irreconcileable to many others. Philosophers of late seem very much inclined to attribute to matter attractions and repulsions of such natures, as suits their particular views, or to deprive the particles of either or both powers in respect of certain sorts of matter, as the nature of the investigation seems to demand; we may farther observe that matter of one kind has been endowed, hypothetically, with the power of placing the particles of another kind of matter at right angles to those of its own. However convenient all this may be, in some respects, it is certain, that without the greatest care it will be attended with a great many inconveniences, and conduce much to promote confusion in the study of nature. An explanation upon established and general principles is always to be preferred, even if it should not, in every point, be so lucid as one founded on a particular hypothesis invented to solve the difficulty. The explanation we have given of this phenomenon

is deemed to be quite satisfactory, and depends on the general principles; and hence it is thought that no particular hypothesis is at all necessary, or that any should be here introduced. In this Treatise, principles the most firmly established, have been applied to explain all the leading facts in the whole range of Natural Philosophy, which have not already been explained on the same principles. Hence if the explanations of the diversified phenomena, here presented to the Reader, appear to agree with the legitimate rules of philosophising, this Work is worthy of especial attention, by all the lovers of Science, and it promises to reward the toils of those who shall labour to place the subject in a still clearer light.

FINIS.

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